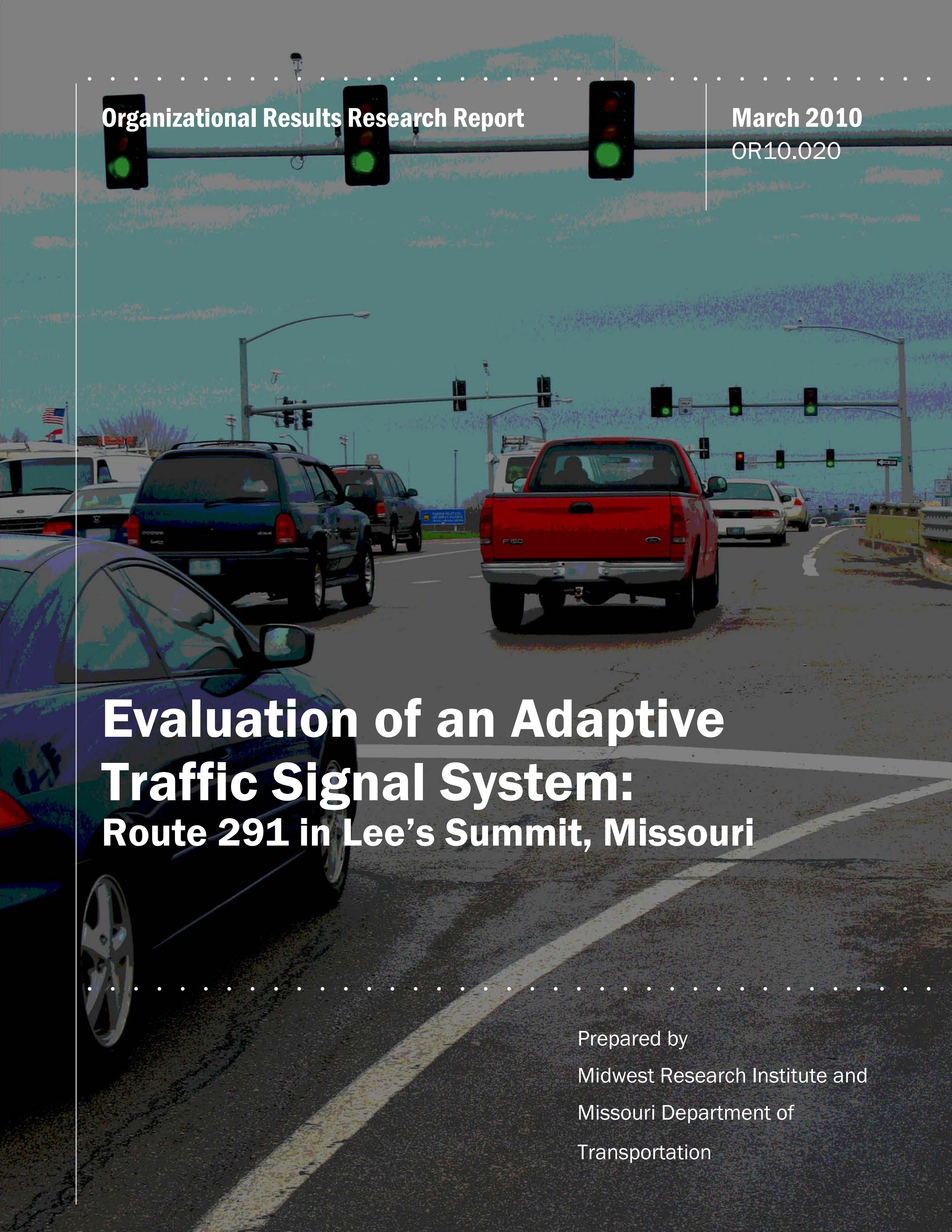


Organizational Results Research Report

March 2010
OR10.020

Evaluation of an Adaptive Traffic Signal System:
Route 291 in Lee's Summit, Missouri

Prepared by

Midwest Research Institute and

Missouri Department of Transportation

FINAL REPORT

Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri

Prepared for
Missouri Department of Transportation
Organizational Results

by

Jessica M. Hutton, Courtney D. Bokenkroger, and Melanie M. Meyer

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

MRI Project 110637
MoDOT Project RI 08-026

March 2010

1. Report No. OR 10-020	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri		5. Report Date March 2010
		6. Performing Organization Code
7. Author(s) Jessica M. Hutton, Courtney D. Bokenkroger, and Melanie M. Meyer		8. Performing Organization Report No. 110637
9. Performing Organization Name and Address Midwest Research Institute 425 Volker Boulevard Kansas City, MO 64110		10. Work Unit No.
		11. Contract or Grant No. RI 08-026
12. Sponsoring Agency Name and Address Missouri Department of Transportation Organizational Results P.O. Box 270-Jefferson City, MO 65102		13. Type of Report and Period Covered Final Report: Nov. 2008 to Feb. 2010
		14. Sponsoring Agency Code MoDOT

15. Supplementary Notes
The investigation was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract
An adaptive traffic signal system was installed on a 12-signal, 2.5-mi arterial in Lee's Summit, Missouri in the Spring of 2008. An evaluation of travel time, delay, number of stops, fuel consumption, and emissions was conducted, which compared operational measures taken before implementation of the system to the same measures taken 1 month and 5 months after implementation. The evaluation found that travel time through the corridor decreased from 0 percent to 39 percent (as much as 2.5 minutes for some time periods), depending on time of day and direction of travel. In the southbound direction of travel, a statistically significant decrease in travel time was found during each of the study time periods, which included AM peak, morning off-peak, noon peak, PM peak, and night off-peak. In the northbound direction of travel, the AM peak and morning off-peak periods saw no statistically significant change in travel time, while all other periods saw a decrease. Improvements were greater in the southbound direction of travel because the previous timing plan favored travel in the northbound direction, especially during the morning. Decreases in the number of stops, fuel consumption, emissions, and time spent in congested conditions decreased during the time periods when travel time decreased. Minor-approach delay was measured at four intersections along the study corridor that represented a range of minor-street approach volumes. Most changes in minor-street delay ranged from a decrease of 3 seconds to an increase of 12 seconds. The change in minor-street delay did not appear to be related to approach volume, but increases in minor-street delay did correspond to intersections and times of day when mainline delay was most improved. The evaluation results indicate that the adaptive traffic signal system is effective in reducing travel time, delay, number of stops, fuel consumption, and emissions for traffic traveling through the corridor. The increase in delay to minor-street traffic was more than offset by the decrease in major-street delay.

17. Key Words	18. Distribution Statement
Adaptive traffic signal system, traffic signals, evaluation, travel time, delay	No restrictions. This document is available to the public through National Technical Information Center, Springfield, Virginia 22161

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	86	

Acknowledgement

This draft final report was prepared for the Missouri Department of Transportation (MoDOT) under the requirements of the MoDOT project titled, “Adaptive Signal Timing Research Along Route 291 in Kansas City, Missouri.” Field work was completed by Jessica Hutton, David Gilmore, John Ronchetto, Mitchell O’Laughlin, Antwan Pettiford, and Brian Heckman of Midwest Research Institute (MRI). Volume data during the after period was collected by Citywide Traffic Services, Inc. This report was prepared by Ms. Jessica M. Hutton, Ms. Courtney D. Bokenkroger, and Ms. Melanie M. Meyer of MRI, with review performed by Mr. Douglas W. Harwood, Ms. Ingrid B. Potts, and Ms. Karin M. Bauer, also of MRI. The report presents the results of the evaluation of the InSync adaptive traffic signal system on Route 291 in Lee’s Summit, Missouri.

Contents

Appendices

Figures

Tables

Summary

In March 2009, the Missouri Department of Transportation (MoDOT) installed a new adaptive traffic signal system along the MO 291 corridor between I-470 and US 50 in Lee's Summit. This was MoDOT's first installation of the InSync system, developed by Rhythm Engineering, and the 12-signal MO 291 corridor included more signals than any previous installation of the system. MoDOT engaged Midwest Research Institute (MRI) to evaluate the system's performance by comparing operational measures taken before the implementation of the system to the same measures taken 1 month and 5 months after implementation. These measures included:

- travel time runs through the corridor
- delay experienced by drivers through the corridor and at individual intersections
- vehicle emissions
- fuel consumption
- number of stops
- minor-street delay at four intersections along the corridor

In addition to these measurements, MRI also collected volume data along the corridor to ensure that changes in these measures were not due to a change in volume. Finally, a turning-movement count was conducted at Chipman Road for comparison with traffic counts collected by the InSync detection cameras.

The results of the comparison of travel time runs indicated the following:

- Travel times through the corridor were reduced by 0 percent to 39 percent.
- The morning off-peak and noon-peak period in the southbound direction of travel experienced the travel time improvements of over 140 seconds (nearly 2.5 minutes).
- No statistically significant difference in travel times was found for northbound travelers during the AM-peak and AM-off-peak periods, most likely because the previous timing plan favored these travelers.
- The average number of stops through the corridor, fuel consumption, and emissions were reduced for every period where travel times were reduced.
- Changes in the average number of stops made by vehicles traveling the length of the corridor ranged from an increase of 0.1 stop per trip (17 percent) to a decrease of 4.3 stops per trip (95 percent).
- Fuel consumption ranged from an increase of 0.01 gallon per vehicle per trip (4.5 percent) to a decrease of 0.03 gallon per vehicle per trip (21.4 percent).
- The change in vehicle emissions (estimated for HC, CO, and NO_x) ranged from an increase of 9 percent to a decrease of 50 percent.
- The change in average speed ranged from a decrease of 0.2 mph to an increase of 15.5 mph (from 25.5 mph to 41 mph).

Traffic volume counts did not show a uniform increase or decrease in volumes. When volumes were summed across all sites through all the time-of-day study periods, the total-before period and after-period volumes were within 4 percent of one another. Therefore, reductions in travel time and delay do not appear to have resulted from any change in traffic volume through the corridor.

The minor-street delay study at four intersections (eight minor-street approaches) indicated that average delay per vehicle increased after the installation of the InSync system. Changes in minor-street delay from the before period to the after periods ranged from a decrease of 20 seconds to an increase of 18 seconds, with most falling between a decrease of 3 seconds to an increase of 12 seconds. The change in delay did not appear to be related to approach volume. In general, the intersections and time periods that saw the greatest increase in minor-street delay were those that saw a significant decrease in delay for the mainline through-moving vehicles.

The 12-hour manual turning movement count at Chipman Road was plotted against the turning movement count collected by the InSync system's detection cameras. The manual and automated counts produced similarly shaped graphs for each turning movement, but the cameras tended to produce higher counts than were observed manually. Total volume by approach ranged from 5 percent to 53 percent higher when counted by the cameras than when counted manually. Discrepancies in individual turning movements ranged from –2 percent to 94 percent. The counts were closest for the north and southbound through movements, where differences were 2 percent or less.

The evaluation results indicate that the adaptive traffic signal system is effective in reducing travel time, delay, emissions, fuel consumption, and number of stops by traffic in the corridor. There may be some increase in minor-street delay, but this is more than offset by the decrease in major-street delay. While a detailed benefit-cost analysis was not included in the scope of this study, it appears that installation of the adaptive traffic signal system was a good investment for MoDOT.

Installation of adaptive traffic signal systems are recommended for further consideration for corridors where traffic demand changes quickly or in an unpredictable manner, where traditional timing plans are unable to accommodate coordination in two directions of travel, or where travel times are 50 percent or more higher than free flow travel times after signal timing plans have been optimized.

Section 1. Introduction

1.1 Background

An adaptive traffic signal system was installed by the Missouri Department of Transportation (MoDOT) along a 2.5-mi corridor on Missouri Route 291 (MO 291) in Lee's Summit, Missouri, between Mulberry Street, located approximately 0.7 mi south of Interstate Route 470, and US Route 50. The corridor includes 12-signalized intersections. The adaptive traffic signal system selected for installation in the corridor was the InSync system, developed by Rythym Engineering. The system was installed to reduce travel time and delay along the corridor. It was also expected to reduce fuel consumption and vehicle emissions and to decrease the average number of stops a through vehicle makes when traveling through the corridor. The developers of InSync claimed that the system would provide the added benefit of reducing delay for vehicles entering or crossing the corridor from a minor street.

The existing signal system (prior to the implementation of the adaptive system) along MO 291 was a fully actuated system with camera detection at the stop bars. This research did not evaluate the optimization of the existing signal timing, but MoDOT district office staff indicated that this corridor had been observed and retimed relatively frequently, and that—despite the effort to optimize the system—the corridor remained congested during the peak periods. It was assumed that no significant improvements could be made by retiming the signals yet again.

The adaptive traffic signal system was installed in the Spring of 2009. Signal controllers were upgraded, fiberoptic connections were laid between the signals, and new cameras were installed just prior to the installation of the system.

When the InSync system was installed, it was a relatively new system, deployed only in a few other locations in the region. The MO 291 corridor was the longest corridor where it had been installed. MoDOT wanted to evaluate the effects of the system on travel time, delay, and a variety of other measures to determine whether or not the system was a good investment for other locations around the state.

1.2 Research Objective and Scope

The objective of the project was to evaluate the traffic operational effectiveness of the adaptive traffic signal system installed on MO 291 in Lee's Summit, Missouri, and to provide recommendations regarding future use of the system in other locations. The evaluation was based on comparison of traffic operational field data collected both before and after deployment of the adaptive signal system. Measures of effectiveness compared between periods before and after system implementation included travel time, stop frequency, stopped delay, minor-street delay, traffic speed profile, cycle length, fuel consumption, and emissions.

The evaluation was designed to provide information about the traffic operational and environmental benefits provided by the adaptive signal system for the MO 291 corridor. The results of this study will be useful for determining the suitability of the system for similar corridors.

1.3 Organization of This Report

Section 2 of this report provides a brief literature review of adaptive signal systems that have been developed in the United States and abroad. It includes a background of the development of adaptive traffic signal systems and a summary of several case studies of systems implemented in the United States.

In Section 3, a detailed discussion of the before and after field studies is provided. This section includes the rationale for what data elements were collected and the methods by which they were gathered. Field studies included travel time runs, minor-street delay studies, volume counts, and a manual turning movement count. Field measurements of travel time, number of stops, time spent in congestion, fuel consumption, emissions and side street delay from each of the three study periods are presented in tables.

Section 4 describes the results and analysis of the field studies, including a statistical comparison of travel time and delay between the before and after periods. Changes in the fuel consumptions, emissions, number of stops and congested time are also presented. A discussion is provided of the time of day, direction, and location along the corridor where improvements are most and least prevalent. Changes in minor-street delay at the eight approaches studied are also presented.

Section 5 documents MoDOT's experience with the system, including customer calls to MoDOT regarding system malfunction (or perception of malfunction) prior to and after the installation of the system. It also includes observations from the Lee's Summit Police Department regarding the system's effect on red-light violations and safety.

Section 6 presents the conclusions of the research. It also provides a discussion of the limitations of this research, suggestions for future study, and recommendations for future use of the InSync system.

Finally, Section 7 provides a reference list for sources consulted for the literature review.

Section 2.
Literature Review

The literature review presented here provides a brief history of the development of adaptive signal systems and then presents a sampling of case studies of locations where adaptive systems have been evaluated.

2.1 History and Background

Adaptive traffic signal systems use algorithms that gather real-time information to optimize timing plans by changing the length and sequence of the phases that are called at each signal in the system and shifting the offsets between intersections to serve current traffic demand. Adaptive signal technology has been available for over three decades, but has not been widely implemented in the United States. The first adaptive technologies were developed in the United Kingdom and Australia. The Split, Cycle, Offset Optimization Technique (SCOOT) was developed initially in the late 1970, by the Transportation Research Laboratory in England. Also in the 1970, the Sydney Coordinated Adaptive Traffic System (SCATS) was developed by the Road and Traffic Authority of Australia. Both systems have been implemented around the world and are the most widely recognized and implemented adaptive signal systems currently available. As of 2000, SCATS was in use in Oakland County, Michigan; Hennepin County, Minnesota; and Durham, North Carolina; and SCOOT systems were being used in Arlington, Virginia; Minneapolis, Minnesota; and Anaheim, California (1). By 2007, adaptive traffic signal systems were operating in more than 30 locations in the United States.

The development of several Adaptive Control System (ACS) prototypes has been sponsored by the Federal Highway Administration (FHWA) in the United States over the past 25 years. These include OPAC (Optimized Policies for Adaptive Control), designed for oversaturated conditions; RHODES (Real-Time Hierarchical Optimized Distributed Effective System), designed for undersaturated conditions; and RTACL (Real-Time Traffic Adaptive Control Logic), designed for networks of streets (1). These systems have been field tested in Reston, Virginia; Seattle, Washington; and Chicago, Illinois; respectively. Results of these tests were not promising. RTACL did not meet expected performance measures. OPAC, both in the field and in simulation, actually increased delay and travel time in some instances, and RHODES reduced cycle lengths, but did not show any significant difference in arterial travel times (2).

In cooperation with signal controller manufacturers, FHWA developed Adaptive Control Software Lite (ACS Lite) as a scaled-down version of its ACS. ACS Lite is licensed by Seimens and can be integrated with four controller manufacturers; implementations of the system on different control types began in 2005. Each controller type was tested with ACS Lite in a field location, and reductions in delay, number of stops, and fuel consumption were realized at two locations, while the other two locations are still collecting data or are in development (3). The goal of ACS Lite is to automate signal timing adjustment and to be widely deployable for arterials with closed loop systems. It is designed as a low-cost alternative to high installation and operating costs associated with some adaptive systems.

The InSync adaptive traffic signal system was first implemented in 2007, in Little Rock, Arkansas. Two additional deployments were underway by MoDOT on US 71 near the Arkansas border and by the City of Lenexa, Kansas, on College Boulevard, when MoDOT selected the MO 291 corridor for deployment of the InSync system in late 2008. The system has since been implemented, or is under deployment, in at least ten additional locations in Arkansas, Georgia, Kansas, and Missouri. Deployment of the InSync system is currently pending in over 20 locations in more than 10 states.

The InSync system separates itself from other adaptive systems in several ways. First, it plugs into existing signal hardware. In general, new cabinets, controllers, and other equipment are not needed. The system requires only camera detection at the intersection; no upstream or in-pavement detection is required. The plug-in system converts analog signal controller operation to digital controller operation. The system sees each allowable pair of phases as a state, and can choose any allowable state (phase pair) at any time, within defined constraints. This eliminates the concept of cycle lengths and phase sequences, as well as the transition time that signal systems experience as they shift from one timing plan to another.

The InSync system coordinates signals by defining a “tunnel,” or the time in which the signal for a certain phase at an intersection must be green. The tunnel is defined for each signal based on the amount of time it takes for a vehicle to travel from one signal to the next, and can be shifted to allow tunnels to cross at a given location (allowing progression in both directions of travel, or for network grids). Outside of the tunnel, individual controllers are free to call any other allowable phase pair, provided there is sufficient time to meet minimum requirements for green time and clearance time. Priority is assigned based on the demand for each phase and the amount of time that has passed since each phase was last called.

2.2 Case Studies

The City of Gresham, Oregon, implemented the SCATS system on a 1.9-mi corridor of a five-lane major arterial in 2007. The arterial was run without coordination until 1995, at which time a coordinated signal system was implemented. In 2005, the coordinated signal timing plan was updated. Travel time runs were collected at several time periods along the corridor for comparison. These were:

- In 1997, while the system was operating free (that is, without coordination between signals)
- In 1998, under new time-of-day coordinated plans

- In 2004, under free conditions
- In 2004, with old time-of-day plans from 1998
- In 2004, with new time-of-day plans
- In 2007, with time-of-day plans from 2004
- In 2007, while operating under the SCATS system

The comparison of these results indicated that the time-of-day plans degraded over time as volumes changed, leading to increased travel times and delay. While data were not yet available to determine how the adaptive system performed over time, comparison of SCATS to the time-of-day plans indicated an improvement for both directions of travel and for all times of day except the AM peak in the direction of heavier flow. This time period was favored in the time-of-day plan, and was considered to be performing optimally at the time the SCATS system was implemented (4).

In 2007, the network of signals in Park City, Utah, operating under SCATS control, were evaluated by researchers at the University of Utah. The Utah DOT chose Park City for implementation of SCATS in 2005, because it was a fast growing area that was experiencing shifts in demand due to nearby recreational events. Because two signals were added to the system and major construction projects occurred at another signal in between the time the before data was collected and the after study was to be conducted, it was no longer possible to have a valid comparison of the before and after periods. The study was therefore changed to compare the system corridor during periods when SCATS was turned on to periods when it was turned off and the underlying time-of-day plans, with no adaptive adjustments made, would be in use. The study notes that two optimized signal timing systems were being compared during the study, since both the time-of-day and SCATS timing plans had been observed and adjusted to optimal performance before evaluation. A 7.5-mi path through the network was driven many times under both conditions to gather data on travel time. Minor-street delay studies were also conducted. It was found that travel times were reduced by about 2 percent during weekend midday peaks, the weekday PM peak saw 4-percent reductions, and the AM peak had the greatest improvement with reductions over 7 percent. The study also found that stops were reduced, and stopped delay was reduced approximately 20 percent during the weekday (5).

From 1999 to 2001, Los Angeles developed and deployed its own adaptive traffic signal system called ATSC (Automated Traffic Surveillance and Control) at 375 intersections. The City evaluated the system by comparing travel time, stops, and delay from the before period, when time-of-day signal timing plans were used, to the after periods, when the ATSC system was operational. The study indicated that travel time was reduced by nearly 13 percent, stops were decreased by 31 percent, and average delay fell by over 21 percent (6).

The City of Vancouver, Washington, evaluated a 12-signal, 6-lane corridor using the OPAC algorithm in 2005. The OPAC system operates on an individual intersection basis and then coordinates with other intersections on the corridor. Only split optimizations are performed in real time, while cycle lengths and offsets are computed traditionally. While these are evaluated and changed frequently, they are not in real time. The OPAC algorithm also requires traffic data from detectors 10-second upstream of the intersection. Where signals are closely spaced, the requirement is difficult to attain. The study indicated that in one direction of travel, average speeds were increased by 20 percent to 25 percent, but decreased by 8 percent to 16 percent in the other direction. Total delay showed similar results, with one direction of travel experiencing decreases from 31 percent to 44 percent, and the other experiencing increases of 17 percent to 73 percent (7).

The University of Detroit Mercy is currently conducting an evaluation of the SCATS-operated signals. Oakland County, Michigan, began changing intersections from fixed-time control to SCATS control in 1992. Because data prior to 1992, is unavailable for the study, a comparative parallel study will be used to conduct a statistical experiment. With the availability of many years of operational data, a cost-benefit evaluation will be conducted that includes installation and maintenance costs as well as congestion and safety benefits (8).

This research represents the first formal statistical evaluation of the InSync adaptive signal system.

Section 3.
Data Collection

3.1 Field Study Description

The study corridor included 12-signalized intersections on MO 291 between Interstate 470 and US Highway 50 in Lee's Summit, Missouri. The corridor is approximately 2.5 mi in length, and signal spacing varies from only about 250 ft near the interchange with US 50 to nearly 3,000 ft between the two northernmost signals. Figure 1 shows a map of the corridor with each signalized intersection labeled.

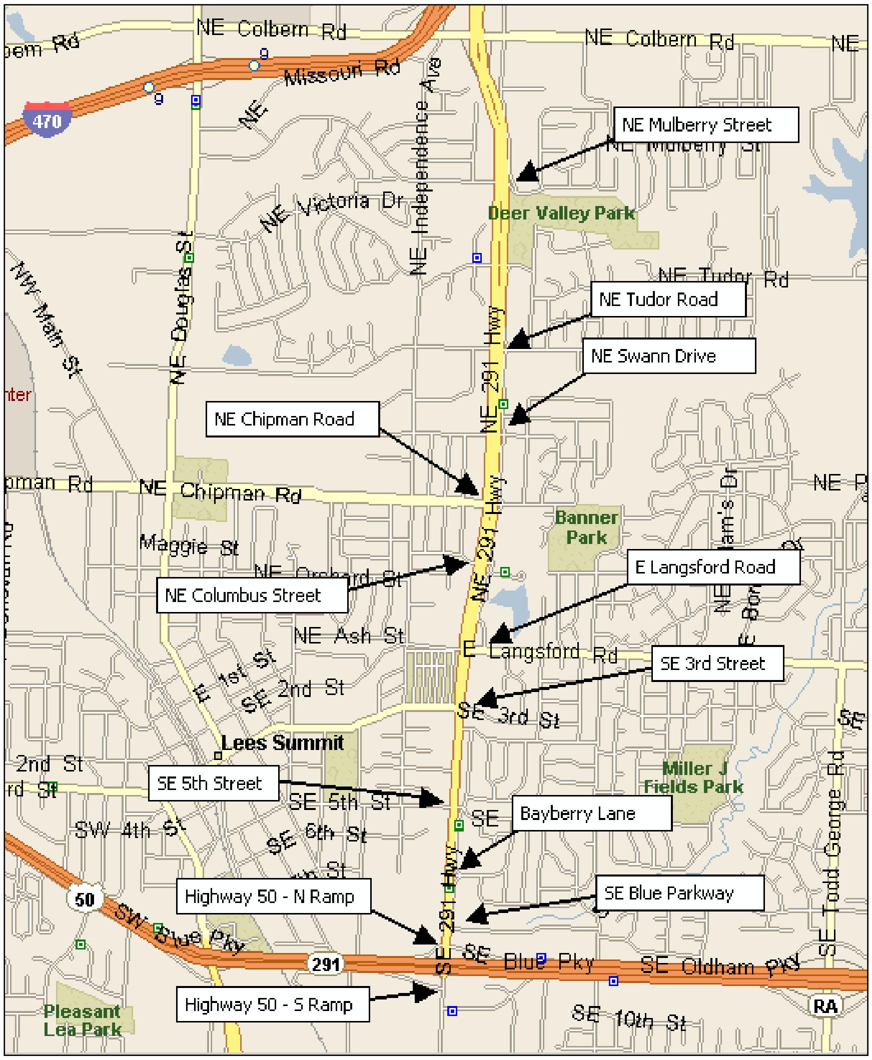


Figure 1. Map of MO 291 Corridor With Signalized Intersections Labeled

Field data were collected along the study corridor during three study periods. The first was conducted in November 2008, prior to the installation of the InSync system. Data collected during this period were used as the baseline for comparing measures of effectiveness. Data were collected again in April/May 2009, approximately 1 month after system installation, and then in September 2009, approximately 5 months after system installation. Each study was conducted during the regular school year on days when school was in session to ensure similar travel patterns between studies.

Field studies included the following data collection activities:

- Travel time runs were conducted through the corridor in both directions during five time-of-day periods (AM peak, AM off-peak, noon peak, PM peak, and night off-peak) on Tuesday, Wednesday, and Thursday of the three study period weeks.
- Minor-street delay studies were conducted using the HCM method on the east-bound and west-bound approaches of four intersections along the study corridor (Chipman, Columbus, Langsford, and Tudor). Each approach was observed during three time-of-day periods (AM peak, AM off-peak, and PM peak) on either a Tuesday or Wednesday during each of the three study period weeks.
- Traffic volume counts were conducted during or immediately following each of the three study period weeks at three locations (north end of corridor, middle of corridor, and south end of corridor) in each direction of travel through the corridor.
- A 12-hour manual turning movement count was conducted at the intersection of MO 291 and Chipman Road in August 2009.

Each of these data collection activities is described in greater detail below. The raw data gathered during each activity is presented in this section, while analysis of the data and results are presented in the next section.

3.2 Travel Time Runs

The travel time study involved measuring the time required for each of a series of vehicle runs through the corridor. Four vehicle runs in each direction of travel were conducted on each of 3 days (Tuesday, Wednesday, and Thursday) during each of the following time periods:

AM Peak (7:30 am to 8:30 am)
AM Off Peak (9:00 am to 11:00 am)
Noon Peak(12:00 pm to 1:00 pm)
PM Peak(3:00 pm to 6:00 pm)
Night Off Peak(10:30 pm to 11:00 pm)

Travel times were measured using a laptop computer running the PC-Travel software connected to a GPS receiver mounted on the roof of the vehicle, as shown in Figure 2. The driver was able to stop and start the data collection from safe locations while the vehicle was stopped and was not required to take any additional action while the vehicle was moving. The software gathered location information from the GPS receiver at 1-second intervals and calculated vehicle speed through the corridor based on this information. The boundaries of the travel time runs were the midpoints of the intersection of MO 291 with Mulberry Street on the north end and the eastbound ramp terminal at the interchange at US 50 on the south end.

Figure 2. GPS and Software Setup in Vehicle to Record Travel Times

The drivers conducting the travel time runs were instructed to use the “floating car method,” in which the drivers attempt to travel with the flow of traffic, changing lanes so as to pass as many cars as they are passed by. This method is used so that the travel times collected are representative of the travel time of the average vehicle traveling through the corridor. When intersections are closely spaced and traffic is heavy, lane change opportunities become limited. Traffic in the right and left through lanes may flow at different speeds, depending on the number of vehicles planning to turn at upcoming intersections, and the driver performing the travel time run may be “stuck” in a lane. While this condition may result in travel times that do not represent the average car, averaging many travel time runs for the same time period will help eliminate the bias that may be present in individual runs. Table 1 shows the number of travel time runs that were completed during each of the time periods, in each direction, for each study period.

Table 1. Number of Completed Travel Time Runs During Each Study Period

Direction	Time of day	Before period	First after period	Second after period
NB	AM peak	12	12	12
	AM off peak	12	13	12
	Noon peak	11	12	12
	PM peak	13	10	12
	Night off peak	12	12	12
SB	AM peak	12	12	12
	AM off peak	12	12	12
	Noon peak	10	12	12
	PM peak	11	10	12
	Night off peak	12	12	12

Tables 2 and 3 below present summary statistics for the travel runs described above. The statistics include the travel time for each segment averaged over all the runs for a given time period and direction of travel, as well as other measures of effectiveness such as average speed, total delay, congested time, fuel consumption and emissions. The measures of effectiveness presented here for the corridor include:

Travel time—the average time in seconds for the vehicle to travel through the corridor from the center of the first intersection to the center of the last intersection, calculated separately for each direction of travel.

Average number of stops—the number of times the vehicle speed fell to 3 mph or below along the corridor, averaged over all the runs for each direction of travel during each time period.

Average speed—the length of the corridor divided by the average travel time for the corridor, expressed in mph.

Total delay—the travel time through the corridor for each run minus the time it would have taken the vehicle to travel through the corridor if it were able to travel at the normal speed of traffic, averaged over all runs for a given time period in each direction of travel. The normal speed of traffic is defined here as the posted speed limit of 45 mph.

Stopped time—the average number of seconds per run spent traveling at a speed less than or equal to 3 mph. The speed that constitutes a “stop” was defined as 3 mph for consistency with travel time studies conducted by the Mid-America Regional Council (MARC).

Congested time—similar to stopped time, the average number of seconds per run spent below a user-defined “congested speed.” For this study, both a congested speed of 20 mph (which corresponds with MARC’s definition of congested speed) and a congested speed of 30 mph were used to represent varying degrees of congestion.

Fuel consumption—average fuel consumption in gallons for a passenger car was estimated by the PC-Travel software based on travel time and average speed. While this number may not truly represent the amount of fuel consumed by a “typical” vehicle traveling through the study corridor, it is a valid measure for comparison of relative fuel consumption from one study to the next. In other words, the change in fuel consumption within the study corridor from the before period to the after period is considered a measure of effectiveness rather than the estimated amount of fuel consumed during each study.

Emissions—average emissions of volatile organic compounds (VOC), carbon monoxide (CO), and oxides of nitrogen (NO_x), each measured in grams, were derived from speed and acceleration by the PC-Travel software. As in the case of fuel consumption, this number may not truly represent the level of emissions for a "typical" vehicle traveling through the study corridor, but it is a valid measure for comparison of relative fuel consumption from one study to the next.

Figures 3 and 4 are boxplots illustrating a summary of the travel times measured for the runs in the northbound and southbound directions, respectively. The summary statistics shown on the boxplots by time-of-day and study period include:

- The minimum and maximum data values indicated by the lines extending from the box
- The middle 50% of values indicated by the shaded box
- The median value indicated by the dividing line in the box
- The average value indicated by the dot for the before period data and an open or full square for the after period data

The information presented in the table below the boxplot is presented in columns that correspond with the time-of-day and study periods shown on the x-axis of the boxplot just above the table and includes the minimum, maximum, median and mean values of travel time, as well as the number of completed runs and the standard deviation of the travel times, by time or day for each direction of travel.

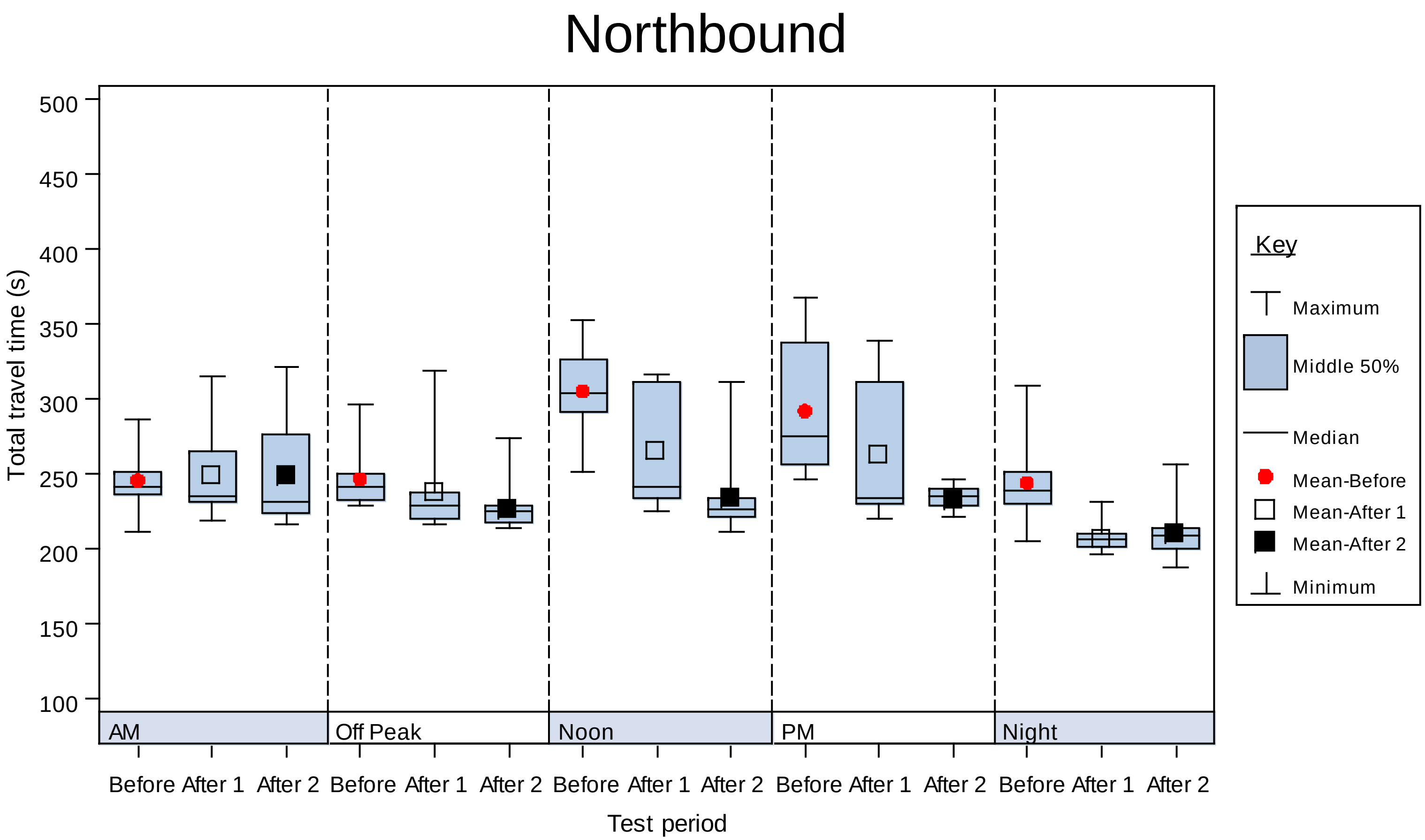
A visual inspection of the data for the northbound runs shown in Figure 3 indicates that in the AM-peak period, the average travel time remained fairly steady, while decreases in average travel time from the before to the after study periods are clearly evident in the noon, PM-peak, and night-time periods for the northbound direction of travel. The southbound runs shown in Figure 4 illustrate that larger differences are seen in the AM-peak and morning off-peak periods in the southbound direction than were seen in the northbound direction. Noon and PM-peak periods also show decreases in average travel time, while the difference in the night-time period is not as pronounced. The differences between the two directions of travel are probably due in large part to the previous signal timing, which favored the northbound direction of travel in the morning. A statistical evaluation of the differences between the before and after periods for each time of day and direction of travel is presented in the next section.

Table 2. Summary of Northbound Runs

Time period	Test period	Travel time (sec)	Average number of stops	Average speed (mph)	Average delay (sec)	Average time ≤ 3 mph	Average time ≤ 20 mph	Average time ≤ 30 mph	Average fuel consumption (gal)	Average HC (g)	Average CO (g)	Average NO_x (g)
AM Peak	Before	246.1	0.6	37.6	41.7	7.6	21.9	40.8	0.11	9.7	113.0	5.86
	After 1	250.3	0.8	37.3	45.6	12.9	25.0	43.6	0.11	9.9	112.1	6.02
	After 2	250.0	0.6	37.6	45.4	13.4	28.5	50.0	0.12	10.7	123.6	6.73
AM Off Peak	Before	247.1	0.8	37.5	42.7	7.0	20.8	42.8	0.11	10.5	122.6	6.61
	After 1	239.8	0.7	38.9	35.1	8.3	15.5	28.9	0.11	9.2	107.7	5.34
	After 2	227.8	0.1	40.6	23.2	2.2	8.3	22.4	0.11	9.2	111.5	5.5
Noon Peak	Before	305.5	1.8	30.4	100.6	53.4	76.1	100.5	0.12	12.0	132.1	7.3
	After 1	266.7	0.8	35.3	61.8	22.2	33.8	60.0	0.12	11.0	124.0	6.86
	After 2	235.0	0.3	39.6	30.6	6.9	11.5	30.8	0.11	9.5	113.7	5.66
PM Peak	Before	292.4	1.5	32.2	87.6	47.4	67.5	92.8	0.12	11.6	130.7	7.0
	After 1	264.4	1.1	35.8	59.7	25.8	39.6	60.6	0.12	10.8	123.2	6.67
	After 2	234.8	0.2	39.2	30.4	0.3	11.3	34.4	0.11	9.9	117.7	6.2
Night Off Peak	Before	244.5	1.6	38.0	39.8	16.9	35.6	54.9	0.12	11.3	134.1	7.38
	After 1	208.0	0.3	44.3	3.5	0.6	5.8	13.3	0.11	9.0	116.8	5.51
	After 2	211.2	0.3	43.8	6.6	2.7	9.7	19.8	0.11	8.8	108.1	5.3

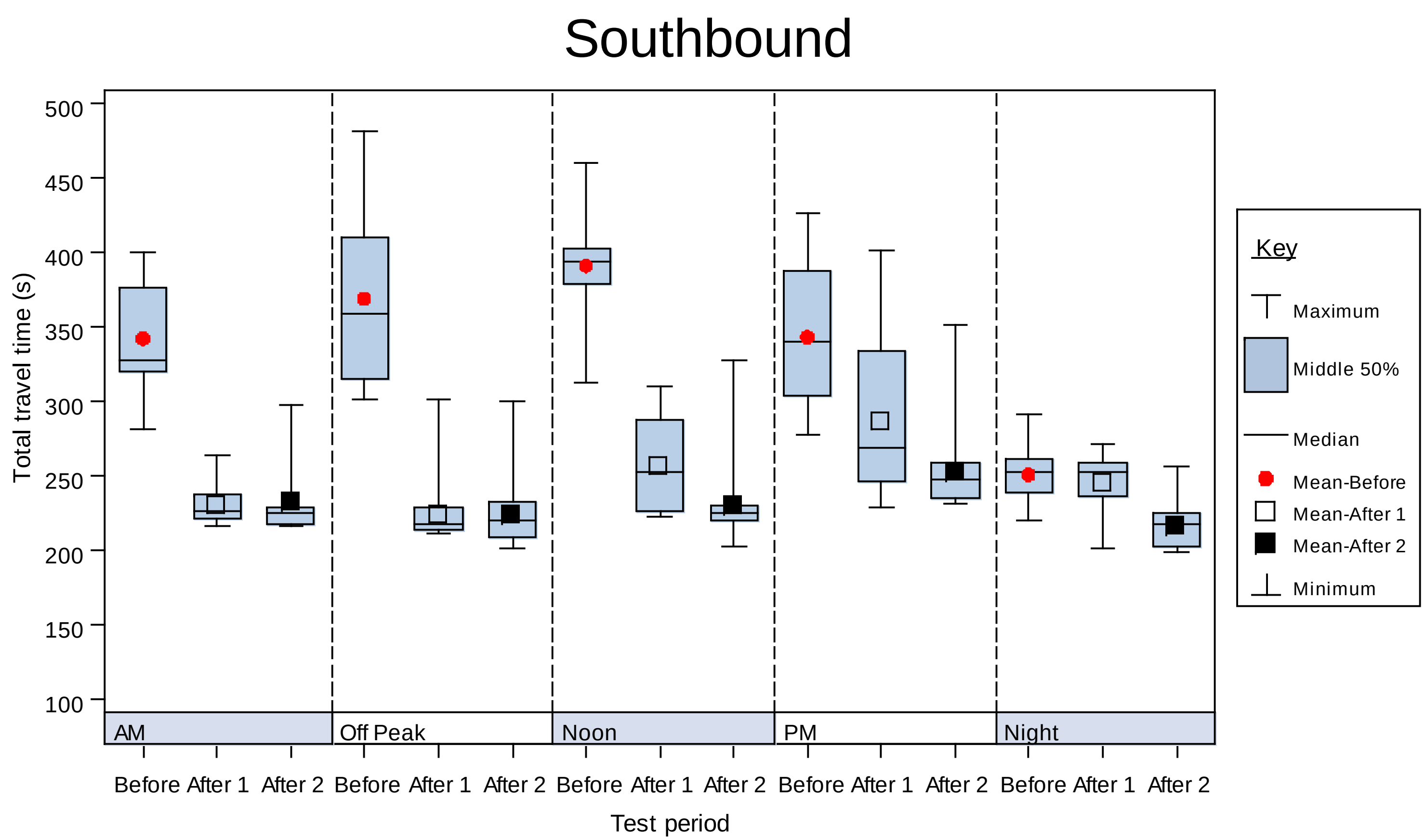
Table 3. Summary of Southbound Runs

Time period	Test period	Travel time (sec)	Average number of stops	Average speed (mph)	Average delay (sec)	Average time ≤ 3 mph	Average time ≤ 20 mph	Average time ≤ 30 mph	Average fuel consumption (gal)	Average HC (g)	Average CO (g)	Average NO_x (g)
AM Peak	Before	342.7	3.9	27.3	137.6	59.3	113.9	158.3	0.13	14.0	137.5	9.08
	After 1	231.3	0.2	39.9	26.9	1.5	7.8	20.5	0.10	8.1	94.3	4.41
	After 2	234.8	0.2	39.7	30.2	9.3	17.0	36.7	0.11	8.5	101.3	4.68
AM Off Peak	Before	369.6	4.6	25.5	164.3	82.2	138.6	188.1	0.13	14.1	137.5	8.80
	After 1	225.9	0.2	41.0	21.7	4.8	6.4	12.4	0.10	7.6	91.7	3.90
	After 2	225.9	0.3	41.1	21.5	5.8	11.4	26.0	0.11	8.6	103.7	4.90
Noon Peak	Before	391.5	4.7	23.8	186	104.7	161.9	204.7	0.14	15.0	146.4	9.36
	After 1	258.2	0.8	36.3	53.3	18.3	29.5	48.8	0.11	9.6	110.0	5.58
	After 2	231.5	0.3	40.3	26.9	3.8	12.8	28.7	0.11	8.9	106.7	5.21
PM Peak	Before	343.6	2.6	27.3	138.5	70.5	112.5	151.2	0.13	12.5	126.5	7.41
	After 1	288.1	1.4	33.0	83.4	25.5	56.2	92.4	0.11	11.1	118.0	6.78
	After 2	254.8	0.9	36.5	50.5	6.2	24.3	53.6	0.11	10.6	119.4	6.62
Night Off Peak	Before	251.2	1.8	36.9	46.5	19.9	42.4	60.8	0.12	9.5	104.1	5.63
	After 1	246.7	1.8	37.6	42.0	18.1	37.3	53.9	0.11	9.3	104.2	5.42
	After 2	217.9	0.7	42.4	13.7	3.5	12.3	23.8	0.11	8.0	93.9	4.55



N	12	12	12	12	13	12	11	12	12	13	10	12	12	12	12
Min	212	219	217	229	216	214	252	225	211	247	220	221	205	197	188
Median	241.5	235.5	231	241.5	229	225	304	241	226.5	275	234	235	239	206	209.5
Max	286	315	322	297	319	274	353	317	311	368	339	247	309	232	256
Mean	246.1	250.3	250.0	247.1	239.8	227.8	305.5	266.7	235.0	292.4	264.4	234.8	244.5	208.0	211.2
Std Dev	20.4	33.3	41.4	21.5	30.9	15.9	26.0	40.4	28.3	45.6	47.5	7.3	26.3	10.2	16.7

Figure 3. Box Plot of Total Travel Time for Northbound Runs by Study Period and Time of Day



N	12	12	12	12	12	12	10	12	12	11	10	12	12	12	12
Min	281	216	216	301	211	202	313	223	203	278	229	231	220	201	199
Median	328	226	225	359.5	217.5	220	394	252.5	225.5	340	269	247.5	253	253	217.5
Max	401	264	298	482	302	300	461	310	328	427	402	352	291	272	257
Mean	342.7	231.3	234.8	369.6	225.9	225.9	391.5	258.2	231.5	343.6	288.1	254.8	251.2	246.7	217.9
Std Dev	41.6	14.3	29.8	55.7	24.9	26.3	38.7	34.7	31.6	46.4	58.1	32.5	18.7	18.7	17.2

Figure 4. Box Plot of Total Travel Time for Southbound Runs by Study Period and Time of Day

Figures 5 and 6 show the speed and cumulative travel time by distance for travel time runs through the entire corridor. They illustrate two examples of the data for discussion here. Similar figures for each time of day and direction of travel are presented in Appendix A. Figure 5 shows travel time runs that were completed during the AM-peak period in the northbound direction, and Figure 6 show runs in the AM-peak period in the southbound direction. This time period was chosen as an example for presentation because clear differences are apparent between the two directions of travel, which are discussed below. The upper half of the figure is a time-distance (or time-space) diagram, while the lower half is a speed-distance diagram. The individual lines in the graphs represent individual travel time runs. Grey lines represent runs from the before period and green lines represent runs from the two after periods. Both graphs use the same horizontal axis, which shows the distance along the corridor in feet, and both graphs track the study vehicle as it moves through the corridor.

In the upper graph in these figures, the slope of the line represents vehicle speed. When the vehicle slows, the steepness of the line increases because more time passes as the vehicle moves from one point along the corridor to another. Vertical jumps in the line indicate that the vehicle had to slow or stop at an intersection. Lines that are smooth with few jumps indicate that the vehicle did not have to slow or stop often. Figure 6 shows clearly that the grey lines “jump” more than the green lines do. The point along the vertical axis where the lines end at the final intersection indicates the total travel time for the run. For this time of day and direction, the before runs have travel times between approximately 280 and 400 seconds, while the after runs have travel times between approximately 200 and 300 seconds. (The actual range of travel times and a statistical analysis of the differences are presented in the next section.)

The lower graph in Figures 5 and 6 shows the study vehicle’s speed as it moves along the corridor. Where the lines dip, the speed is decreasing. The blue horizontal line represents a speed of 45 mph, the posted speed limit. A car experiencing no delay and traveling at the posted speed would have a speed-distance diagram along this blue line.

Figure 5 shows the scenario where the implementation of the InSync system provided the least benefit. In fact, the travel times in the two after periods were slightly longer than in the before-period runs on average, and drivers in the after period had to stop more frequently than they did in the before period. This is most likely because the previous signal timing plan heavily favored the northbound direction of travel.

In contrast, the grey lines in Figure 6 indicate that in the before period, southbound vehicles often had to stop at several intersections along the corridor. The green lines show that in the after period, many of these stops were eliminated. The difference is most obvious at Swann Drive, Chipman Road, 3rd Street, and Bayberry Lane, where there is a high concentration of grey lines dipping toward 0 mph and virtually no green lines dipping in these locations.

Appendix A presents similar diagrams for both directions of travel during each time-of-day period. Section 4 presents the statistical comparison of travel times before and after the InSync system was implemented.

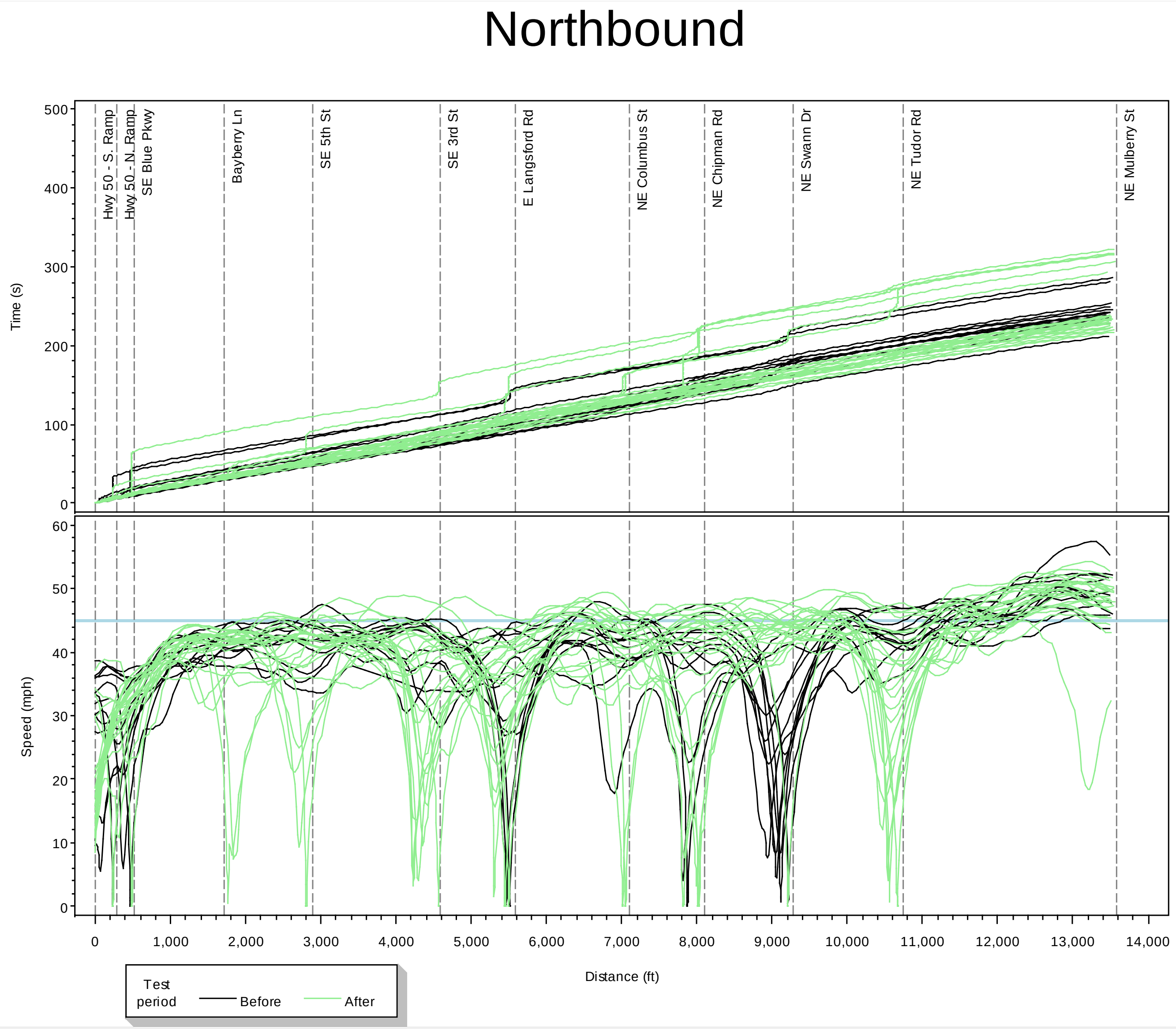


Figure 5. Time-Distance and Speed-Distance Diagrams for Runs in the Northbound Direction During the AM Peak Period

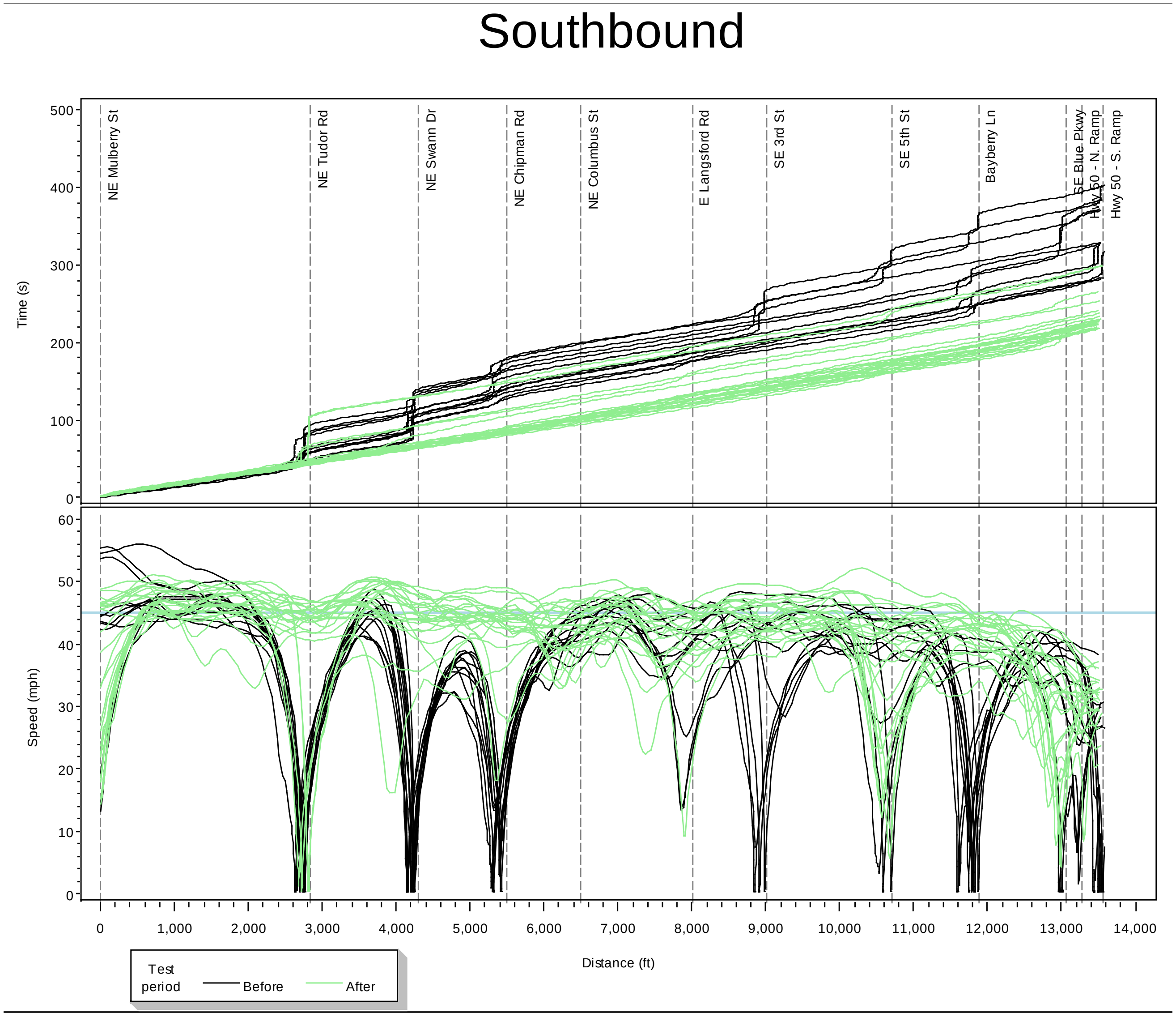


Figure 6. Time-Distance and Speed-Distance Diagrams for Runs in the Southbound Direction During the AM Peak Period

3.3 Minor-Street Delay

Minor-street delay was measured on both minor-street approaches at four selected intersections along the corridor during three time periods (AM peak, AM off peak, and PM peak). The four minor streets where delay studies were conducted are:

- Chipman Road
- Columbus Street
- Langsford Road
- Tudor Road

All of the intersections selected for the minor-street delay study are four-leg intersections. Each intersection was observed on the same day of the week and at approximately the same time of day during each of the after-period studies as during the before-period study. Because of periods of rain during the first after-period study, these observations took place over a 2-week period to ensure uniformity in time-of-day and day-of-week between studies.

The methodology for measuring minor-street delay described in the *Highway Capacity Manual* (HCM) (9) was used with the aid of a Jamar TDC-12 hand-held data collector. The TDC-12 allows the signalized intersection approach delay study to be completed by one data collector, rather than using the two-person method described in the HCM. Figure 7 shows the TDC-12 handheld data collector used to collect minor-street delay data.

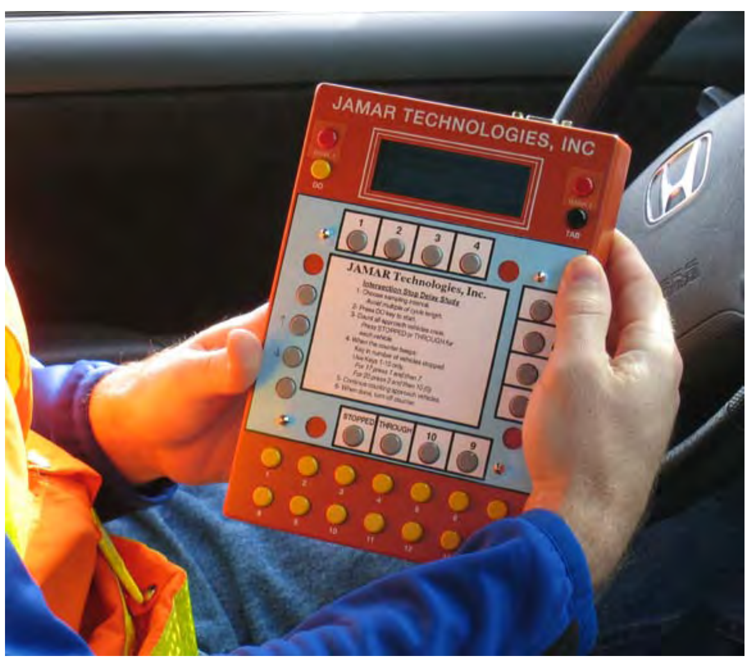


Figure 7. Photo of TDC-12 Handheld Data Collector

The minor-street delay study consisted of two activities. First, a time interval was chosen, and at the end of each interval, all queued vehicles were counted and recorded. For this study, the number of cars queued at the intersection was recorded at 16-second intervals over a 20-minute time period. Next, each vehicle that approached the intersection was recorded as either going through the intersection or stopping at the intersection. The presence of channelized right-turn lanes required the engineers conducting the study to use judgment when recording right-turning vehicles as "through" or "stopped." Because right-turn-on-red movements are permissible at the study intersections and some channelized right-turn lane storage space was available, right-turning vehicles had a lower delay than other vehicles. However, since the study intersections did not have dedicated right-turn lanes with sufficient storage to keep right-turning vehicles and through vehicles separated in the queue, right-turning vehicles could not be removed or recorded separately in the study. Right-turning vehicles that rolled through the red signal indication without having to yield to another vehicle were counted as going through the intersection, while those that stopped or slowed significantly to yield to another vehicle were counted as having stopped.

The results of the minor-street delay study are presented in Tables 4 through 7 below. For each 20-minute study period, the tables show the number of approaching vehicles, the average delay per vehicle, and the percentage of total vehicles that stopped at the signal. In Section 4.6 of this report, the data presented in Tables 4 through7 is presented graphically and the change in delay from the before-period study to the after-period studies is discussed. The potential relationship between approach volume and delay is also explored.

Table 4. Minor-Street Delay at Chipman Road

Approach direction	Study period	Number of observed vehicles			Average delay per vehicle (sec)			Percentage of total vehicles that stopped		
		AM Peak	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**
EB	Before	48	59	154	23.0	16.8	27.0	70.8	84.7	72.7
	After 1	56	77	142	28.9	29.5	23.5	80.4	77.9	73.9
	After 2	62	75	149	30.5	18.6	31.5	77.4	64.0	79.9
WB	Before	34	45	60	20.2	20.3	31.7	79.4	84.4	90.0
	After 1	34	33	48	23.5	26.2	33.3	70.6	84.8	87.5
	After 2	37	30	69	31.1	34.7	34.3	86.5	83.3	76.8

Table 5. Minor-Street Delay at Columbus Road

Approach direction	Study period	Number of observed vehicles			Average delay per vehicle (sec)			Percentage of total vehicles that stopped		
		AM Peak	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**
EB	Before	8	17	34	28.0	14.1	32.9	87.5	70.6	85.3
	After 1	9	12	45	28.4	13.3	34.8	77.8	83.3	80.0
	After 2	7	15	29	20.6	27.7	24.3	71.4	100.0	89.7
WB	Before	34	35	43	32.9	18.3	33.1	91.2	80.0	81.4
	After 1	19	24	49	12.6	18.7	35.9	84.2	87.5	75.5
	After 2	14	42	33	12.6	27.8	39.8	78.6	76.2	81.8

Table 6. Minor-Street Delay at Langsford Road

Approach direction	Study period	Number of observed vehicles			Average delay per vehicle (sec)			Percentage of total vehicles that stopped		
		AM Peak	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**
EB	Before	57	69	152	32.0	34.3	41.9	89.5	92.8	82.9
	After 1	58	64	134	29.5	32.8	41.0	87.9	87.5	82.8
	After 2	51	81	125	31.1	37.7	46.0	84.3	87.7	86.4
WB	Before	265	161	199	19.1	19.8	22.8	75.1	84.5	73.4
	After 1	252	160	171	21.3	19.1	46.3	65.1	71.9	83.6
	After 2	271	158	207	18.4	22.3	35.0	61.6	66.5	69.1

Table 7. Minor-Street Delay at Tudor Road

Approach direction	Study period	Number of observed vehicles			Average delay per vehicle (sec)			Percentage of total vehicles that stopped		
		AM Peak	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**	**AM Peak**	**AM Off Peak**	**PM Peak**
EB	Before	59	143	283	16.0	16.2	27.4	67.8	59.4	69.6
	After 1	89	126	308	25.3	25.3	27.0	72.7	75.4	72.7
	After 2	91	107	284	30.1	23.3	27.3	79.1	76.6	67.6
WB	Before	150	114	184	19.5	21.9	23.7	80.0	80.7	69.0
	After 1	197	92	141	26.7	24.7	30.0	73.6	66.3	70.9
	After 2	193	124	181	25.3	26.3	28.4	56.5	57.3	68.0

3.4 Turning Movement Count

On Thursday, August 20, 2009, a 12-hour manual turning movement count was conducted at the intersection of MO 291 and Chipman Road. The count, which began at 6:30 am and ended at 6:30 pm, was conducted using two Jamar handheld data collection devices. The purpose of this effort was to compare to the counts obtained by the detection cameras that were installed as part of the InSync system to the manual counts. Counts were aggregated at 15-minute intervals, and the 15-minute counts for each turning movement from both systems (Jamar and camera) were plotted together to illustrate the differences. Figures 8 and 9 are presented here as examples of these plots. Figure 8 shows the 15-minute volumes for the southbound through movement on MO 291, and Figure 9 shows the 15-minute volumes for the westbound left-turn movement on the same intersection. An exact match was not expected between the two methods because the clocks were not synchronized, so the 15-minute intervals could not be exactly aligned. A visual inspection of the plots showed that a close match between the two count methods was observed for the through movements on MO 291, while turning movements and movements from the minor approaches were matched less.

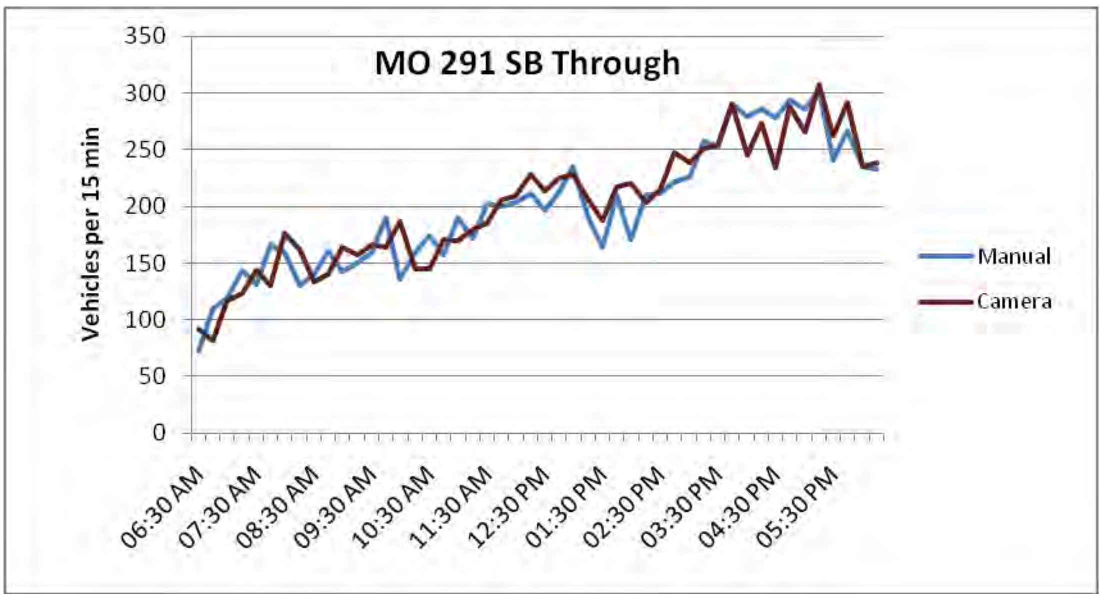


Figure 8. Plot of 15-Minute Volumes for the Southbound Through Movement at MO 291 and Chipman Road

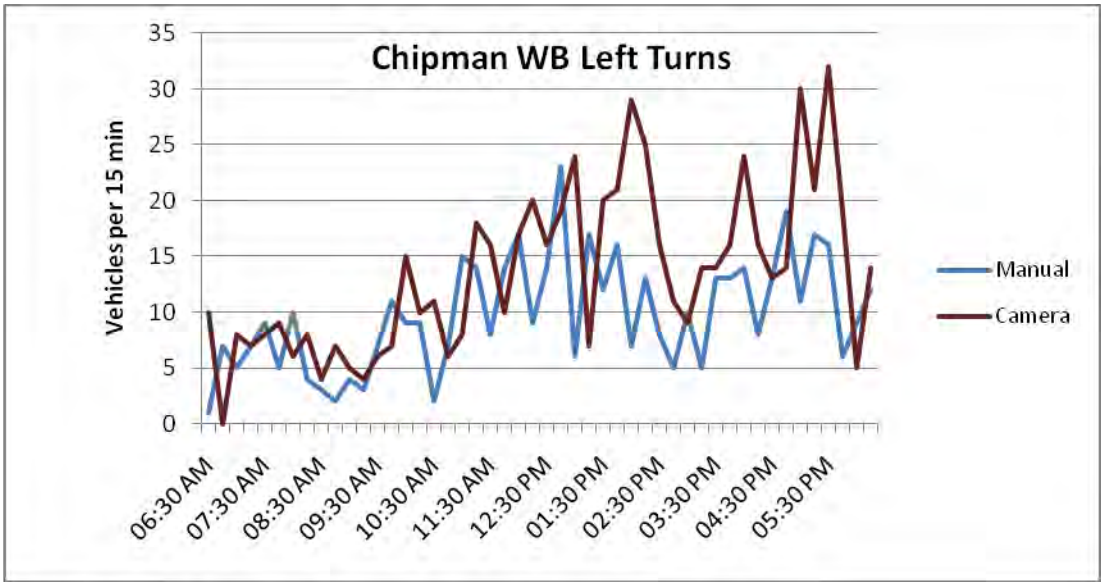


Figure 9. Plot of the 15-Minute Volumes for Westbound Left-Turn Movement at MO 291 and Chipman Road

Appendix B provides the graphs for the remaining turning movements and the 15-minute turning volumes by counting method in table form for comparison. Table 8 provides a comparison of total 12-hour counts by method of collection for each turning movement.

Table 8. Comparison of 12-Hour Totals by Counting Method for Each Turning Movement at MO 291 and Chipman Road

Approach	Direction	Manual count	Camera count	Percent difference
NB	Right	526	1,020	93.9
	Through	9,679	9,483	–2.0
	Left	1,457	1,760	20.8
	Total	**11,662**	**12,263**	**5.2**
SB	Right	1,145	1,700	48.5
	Through	9,529	9,614	0.9
	Left	631	861	36.5
	Total	**11,305**	**12,175**	**7.7**
EB	Right	2,116	2,153	1.7
	Through	697	1,126	61.5
	Left	1,246	1,528	22.6
	Total	**4,059**	**4,807**	**18.4**
WB	Right	447	704	57.5
	Through	672	1,073	59.7
	Left	469	649	38.4
	Total	**1,588**	**2,426**	**52.8**

Table 8 shows the volumes recorded by the camera were generally higher than those recorded manually. For the north and southbound approaches, the camera counts give a volume approximately 5 percent to 8 percent higher than the manual count, with discrepancies of 2 percent or less for the through movements. For the eastbound approach, the camera count is almost 20 percent higher than the manual count, and for the westbound approach, the difference is over 50 percent. Possible reasons for the differences observed between count methods may include:

- Vehicles that straddled the lane line may have been picked up in more than one camera detection zone and therefore may have been counted in more than one lane group. This is likely to occur more often on the minor street, because lane widths are typically more narrow than those on the arterial corridor.
- The counting algorithm used by the camera may count a vehicle more than once if it is present in the detection area for more than a set amount of time.
- Some approaches at this intersection have shared lane groups, and the camera may be unable to correctly identify a vehicle's movement if it is detected in a shared lane.

3.5 Traffic Volume Counts

The research team conducted traffic volume counts using tape switches in both the northbound and southbound directions at three locations on MO 291 in the study corridor during each of the three study periods. The locations where these counts were made include:

- Between Mulberry Street and Tudor Road (Site 1)
- Between Columbus Street and Langsford Road (Site 2)
- Between 5th Street and Bayberry Lane (Site 3)

Traffic volumes were collected at these three strategic locations along the MO 291 corridor to verify that the data collection and analysis for the mainline travel time and side-street delay studies were conducted in similar traffic volume environments. The three data collection locations were geographically spaced to best capture the possible change in traffic volume along the route. The volume data was collected using Unicorn Traffic Classifiers in coordination with ribbon-style tape strips and road tubes.

Traffic volumes (measured as the number of vehicle axles that passed over the tape strip or road tube during the study period) were collected for the before-period study from Tuesday, December 2 to Thursday, December 4, 2009. Traffic volume data obtained during the first after-period study were incomplete and invalid because several tape switches either came off of the pavement during the study or were otherwise destroyed and stopped collecting data. Traffic volumes for the second after-period study were counted during the week of September 21, 2009. Care was taken to ensure that all studies were conducted during the school year on school days with a normal schedule (i.e., no early releases or half days). The data collected represent counts of vehicle axles passing over the sensors. Assuming the mix of vehicles in the traffic stream was constant through all studies, the change in axle count between study periods is proportional to the change in volume between studies.

The data collected during the after-period study are compared to the before-period study in Table 9. The data in the table represent average 15-minute axle counts during the five time-of-day periods studied. These counts do not show a uniform increase or decrease at any given site during any given time period. That is, at every site, volumes increased during certain times of day, and decreased during other times of day. When volumes were summed across all sites through all the time-of-day study periods, the total-before period and after-period volumes were within 4 percent of one another. Therefore, the traffic volumes between the before and after study periods are comparable, and reductions in travel time and delay do not appear to have resulted from any change in traffic volume through the corridor.

Table 9. Comparison of 15-Minute Axle Counts Along MO 291 During Before and After Study Periods

Direction	Site	Study period	AM peak	AM off peak	Noon peak	PM peak	Night off peak
NB	1	Before	543	361	455	478	99
		After 2	434	403	435	512	174
		Percent change	*–20.1*	*11.6*	*–4.4*	*7.1*	*75.8*
	2	Before	506	428	566	522	105
		After 2	526	403	436	507	156
		Percent change	*4.0*	*–5.8*	*–23.0*	*–2.9*	*48.6*
	3	Before	566	473	621	676	100
		After 2	318	332	396	430	151
		Percent change	*–43.8*	*–29.8*	*–36.2*	*–36.4*	*51.0*
SB	1	Before	368	381	466	701	142
		After 2	232	323	464	542	237
		Percent change	*–37.0*	*–15.2*	*–0.4*	*–22.7*	*66.9*
	2	Before	211	282	319	466	83
		After 2	323	361	436	606	190
		Percent change	*53.1*	*28.0*	*36.7*	*30.0*	*128.9*
	3	Before	288	302	403	450	108
		After 2	336	312	406	481	181
		Percent change	*16.7*	*3.3*	*0.7*	*6.9*	*67.6*

Section 4.
Analysis and Results

The effectiveness of implementing the adaptive traffic signal system was evaluated by comparing before and after total travel time through the corridor and delay for segments of the corridor. All comparisons were made by direction of travel and time of day.

4.1 Travel Time through the Corridor

The total travel time for each run through the corridor was used as the primary measure of effectiveness. Travel time was measured from the center of the first intersection to the center of the last intersection encountered during the run. Initial tests were performed to ensure average travel times did not significantly differ by day of week or between the two after periods and variability in travel times did not significantly differ between the two after periods or between the before and combined after periods (not presented). None of these tests were statistically significant, indicating no significant differences between the two after periods or between the 3 days of the week during which measurements were taken were found.

Because there were no statistically significant differences between the two after periods or between the days of the week, all of the before-period and after-period data could be pooled for analysis. In other words, these statistical tests verified the legitimacy of considering the data from both of the after-period studies together in one data set, allowing a before-after analysis. The similarity of the two after-period study results may indicate that little driver acclamation was needed to adapt to the new system, or that it happened quickly, within the first month of implementation and prior to the first after-period study.

Once the data from the two after-period studies were pooled, two-sample t-tests were used to compare the average before and combined average after period travel times by time period. The results are shown in Table 10 for the southbound direction and in Table 11 for the northbound direction. Travel time differences that were statistically significant at the 95 percent confidence level (P-value less than 0.05) are shown in bold.

Table 10. Changes in Travel Time in Northbound Direction

	Travel time (sec)				
Time period	Before	After	Difference	Standard error	P-value
AM Peak	246	250	4	11.5	0.724
AM Off Peak	247	234	–13	8.4	0.130
Noon Peak	306	251	**–55**	12.6	**<.001**
PM Peak	292	248	**–44**	13.7	**0.003**
Night Off Peak	244	210	**–34**	6.6	**<.001**

Table 11. Changes in Travel Time in Southbound Direction

Time period	Travel time (sec)				
	Before	After	Difference	Standard error	P–value
AM Peak	343	233	**–110**	10.7	**<.001**
AM Off Peak	370	226	**–144**	13.4	**<.001**
Noon Peak	392	245	**–147**	13.6	**<.001**
PM Peak	344	270	**–74**	17.5	**<.001**
Night Off Peak	251	232	**–19**	7.6	**0.019**

Northbound Analysis

Table 10 shows a statistically significant decrease in travel time through the corridor in the northbound direction during the noon peak, the PM peak, and the night off-peak periods. During the noon peak period, the average travel time decreased by nearly a minute, from just over 5 minutes to just over 4 minutes. The PM peak experienced a decrease in average travel time of 44 seconds, from just under 5 minutes to just over 4 minutes. During the night off-peak period, the average travel time fell from 244 seconds to 210 seconds. Assuming no delay (i.e., in a hypothetical situation where all signals are continuously green), a vehicle traveling at a constant speed of 45 mph along the northbound 13,400-ft corridor would have a travel time of about 200 seconds (or about 3.5 minutes). This means that after installation of the InSync system, travelers during the night-off peak period only experience about 10 second of delay on average through the corridor. The average travel times measured in the after-period studies are around 250 seconds during the three peak periods (AM, noon, and PM), which is equivalent to about 50 seconds of delay, about 235 seconds in the morning off-peak period (35 seconds of delay), and 210 seconds in the night off-peak period (10 seconds of delay). These results indicate that during periods of higher volume, longer delay is experienced on average by drivers, and that during periods of very low volume, vehicles expect shorter delay.

During the AM peak, the average travel time increases slightly from the before period to the after period (4 sec), but the difference is not statistically significant. The 13-second decrease in average travel time seen in the morning off-peak period also is not significant. The fact that the InSync system did not significantly reduce travel times in these two periods is most likely due to the fact that the previous signal timing plan heavily favored the northbound direction of travel in the morning timing plans, and that essentially, the coordination during these times was already optimal.

Southbound Analysis

Table 11 shows a statistically significant reduction in average travel time from the before studies to the after studies during all five time-of-day periods. Travel time differences are greater in the southbound direction than in the northbound (comparing the values in Table 11 to those in Table 10), due mostly to the fact that the average before period travel times were greater in the southbound direction than in the northbound direction of travel. On average, the difference between the northbound and southbound before travel times was about 100 seconds during the AM peak and morning off-peak. Once this is recognized, it is not surprising to see travel time reductions about 100 seconds greater in the southbound direction than the northbound during these periods.

The southbound corridor is approximately 13,600-ft long, so a vehicle traveling at the posted speed of 45 mph with no delay would have a travel time of about 205 seconds Travel times in the after period average about 230 seconds during the AM, morning off-peak, and night off-peak periods, which would correspond to only about 25 seconds of delay. The noon peak difference averages about 15 seconds more, and the PM peak about 40 seconds more. The greatest reductions were seen during the morning off-peak and noon peak periods, when travel times were reduced by nearly 2.5 minutes. These two periods had the highest average travel times in the before period, and so had the greatest room for improvement.

Combined Analysis

The combined results of Tables 10 and 11 indicate that time periods with significant delay were improved without adversely affecting other time periods or the other direction of travel. In no instance did an improvement in one direction of travel significantly increase travel time in the opposite direction. The decrease in travel time ranged from no improvement in the AM-peak period in the northbound direction to a nearly 40 percent decrease in the morning off peak and noon peak periods in the southbound direction. Overall, the adaptive traffic signal system has been successful in reducing travel times for vehicles traveling through the corridor.

4.2 Delay at Individual Intersections

Delay was calculated for each intersection. The corridor was broken into segments beginning and ending at the midpoint between intersections. The delay in each of these segments was attributed to the intersection within that segment. Because the three intersections on the southern end of the corridor (at Blue Parkway and the US 50 ramps) are so closely spaced, they are analyzed together as a group within one segment. These study segments are illustrated in Figures 10 and 11. These figures are a graphical representation of all of the travel time runs, with distance in feet on the horizontal axis and speed in mph on the vertical axis. The intersections are labeled for reference. As would be expected, vehicle speeds dip just prior to the intersection and are at their highest at the midpoint of the link between intersections. The figure shows the breaks at the midpoints of these links as the beginning and end points of the segment over which total delay was analyzed.

Total delay includes delay introduced by the presence of the signal (control delay) and other delay due to various roadway and traffic characteristics. Control delay includes deceleration as the vehicle approaches a queue or a red signal indication, acceleration away from the signal to get back to free flow speed, and the time spent stopped at a red indication. Total delay is defined as the difference between the time it would take to travel over the segment unimpeded at a constant speed of 45 mph and the observed travel time.

It should be noted that the control delay caused by a particular intersection may extend beyond the endpoints of the segment assigned to that intersection. In these instances, some control delay may be assigned to the signal prior to or immediately following the signal under consideration. In other instances, a vehicle may still be accelerating from the previous signal when it is again forced to decelerate for the next signal, which results in the vehicle never reaching the free flow speed between intersections, and potentially experiencing delay across the entire segment. It is not possible to completely separate the delay caused by one signal from the delay caused by neighboring signals. However, for the purpose of this study, this segmentation is appropriate and a comparison of control delay for each intersection can therefore be made between before and after periods.

Very little travel time data was available south of the intersection at the US 50 ramps on the south side of the interchange or north of Mulberry Street, as is shown in Figures 10 and 11, because the analysis could only extend as far as the shortest run. While some travel time runs collected data beyond the intersections at either end of the corridor, many did not. Thus the information that was collected beyond these limits was not enough to produce reliable before and after comparisons. For this reason, in the southbound direction of travel, delay measured at Mulberry includes only the delay due to accelerating past the intersection and not the delay due to decelerating prior to the intersection. Similarly, the delay at the group of signals at the southern end of the corridor does not include the delay that would be caused during acceleration beyond the southernmost signal. In the northbound direction of travel, the reverse is true at Mulberry and the signal at the eastbound US 50 ramps.

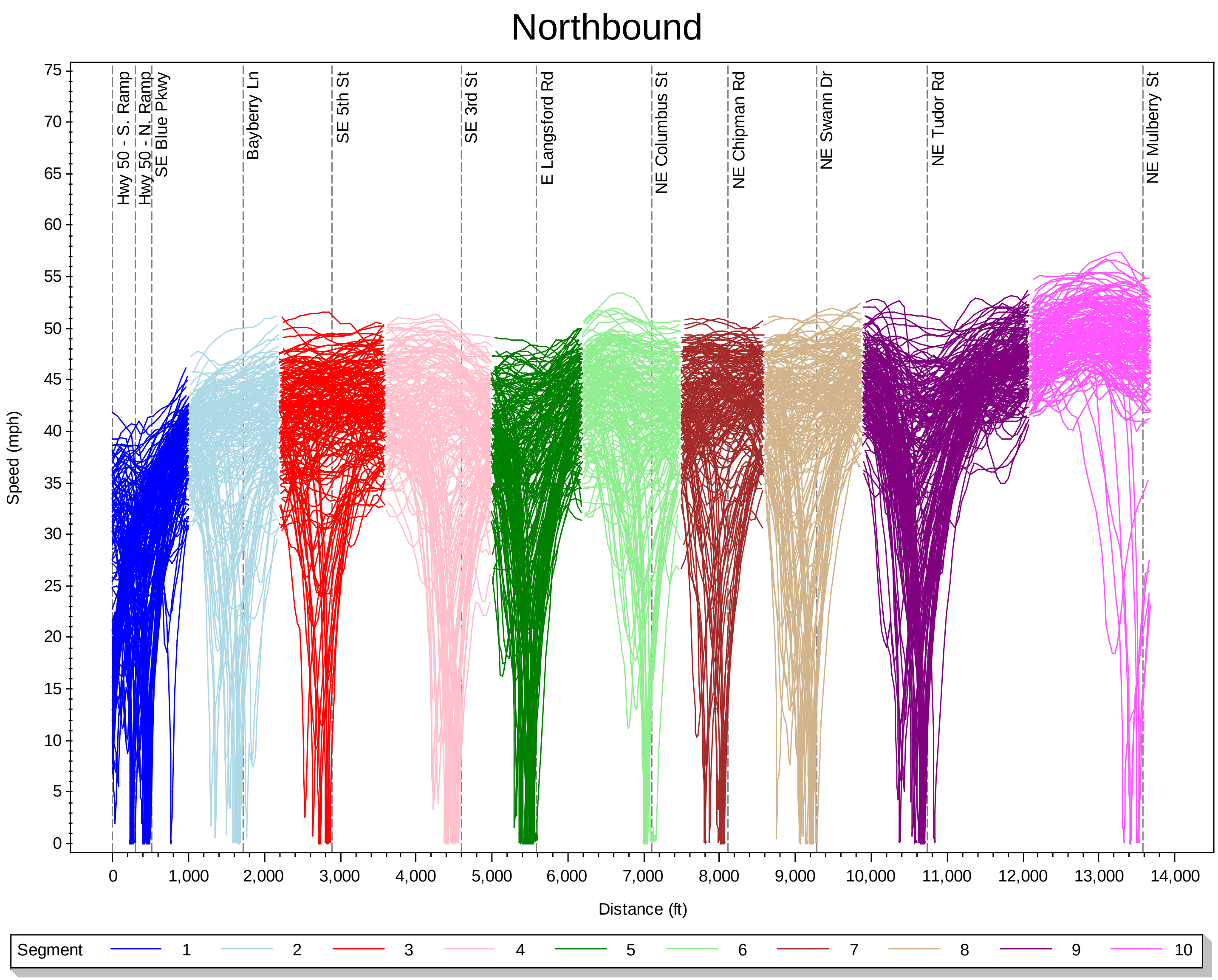


Figure 10. Illustration of Segment Breaks for Delay Analysis in the Northbound Direction of Travel

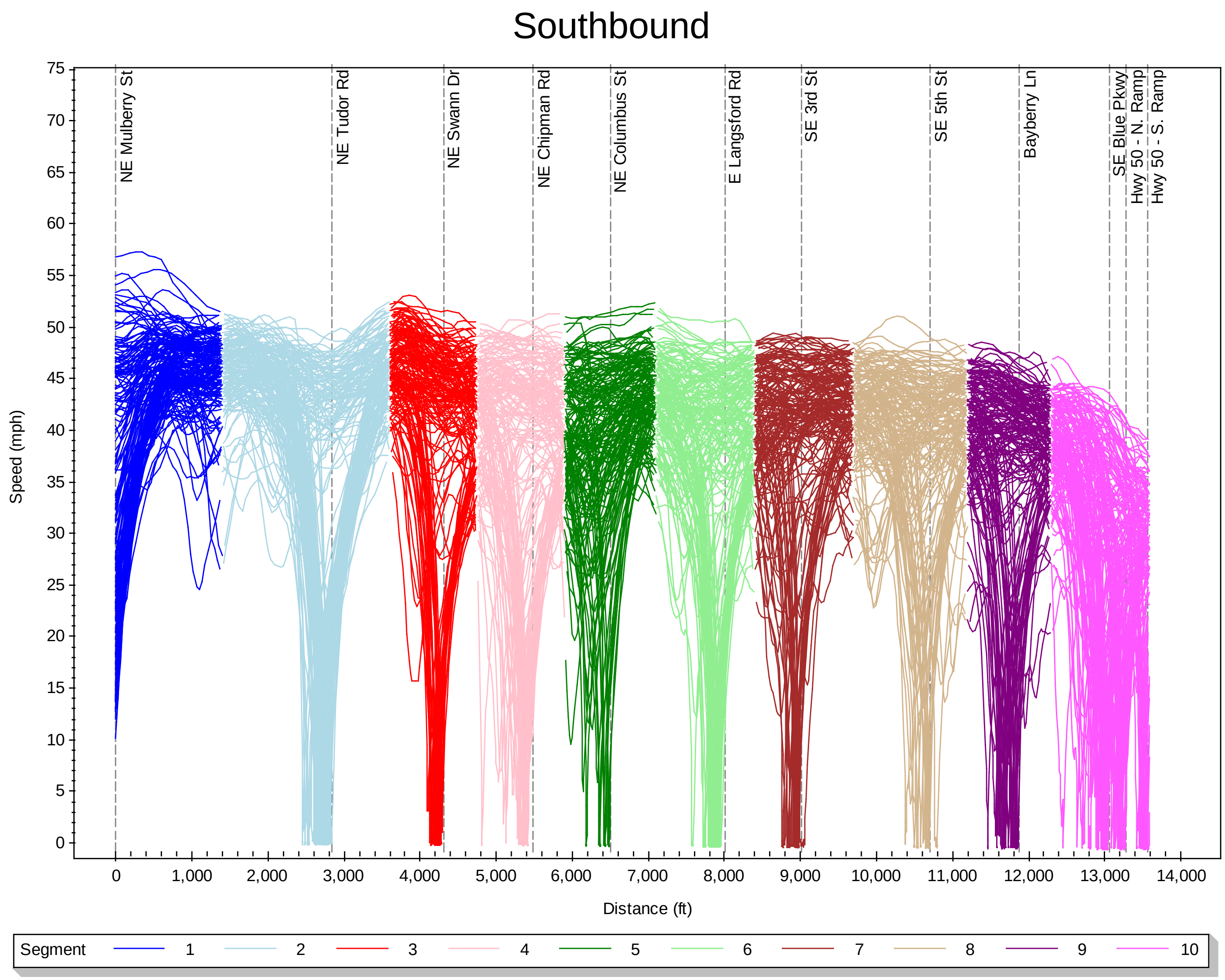


Figure 11. Illustration of Segment Breaks for Delay Analysis in the Southbound Direction of Travel

It is important to note that the first signal in the corridor in either direction of travel is used as a meter to form platoons for progression through the corridor, and that this study does not accurately capture the potential change in the likelihood of stopping at the first signal in the corridor. However, since it is assumed that vehicles arrive at these signals randomly (that is, they are not in a platoon from a previous signal), the likelihood that a vehicle will face a red signal at the intersection is not truly a function of the effectiveness of the system (since, technically, the vehicles have not yet entered the system), but rather a function of the percent green time given to the through movement.

Tables 12 and 13 provide the results of the statistical comparison (using a two-sample t-test) of delay experienced at each intersection (or intersection group) before and after the InSync system installation for each time-of-day period.

The following observations can be made for travel in the northbound direction based on the result in Table 12:

- In the AM peak period, delay is significantly reduced at Swann Road, which, other than the group of intersections near US 50, was the biggest source of delay in the northbound direction of travel.
- Most other intersections showed small increases in average delay during the AM peak, but this increase was statistically significant only at Tudor Road, where average delay increased from 1.7 seconds to 6.1 seconds.
- During the morning off peak, delay was significantly reduced at Langsford, and at the intersection group at the south end of the corridor—the US 50 ramps and Blue Parkway.
- The slight increases in average delay during the morning off-peak period at Tudor Road and Mulberry Street were not statistically significant.
- The noon peak period experienced very large, and statistically significant, reductions in delay at 3rd Street (17.9 seconds) and at Tudor (15.1 seconds). At Langsford, the reduction in average delay during the noon peak was found to be 12.5 seconds, but this was not statistically significant. Other than the grouped signals at the US 50 ramps and Blue Parkway, these three intersections were the points of greatest delay during the noon peak in the before period.
- The PM peak saw large improvements at 3rd Street and Langsford, with statistically significant reductions in average delay of 15.6 and 19.1 seconds, respectively, and again, these were the intersections with the greatest delay during the before period.
- During the night off peak period, significant reductions in travel time were seen at Langsford, Columbus, Chipman, Swann, and Tudor. While these reductions were not as great in magnitude as reductions seen during other times of day (since the night off peak delay in the before period was already relatively low), at three of the five intersections the delay during the after periods was below 1 second.
- The intersection at Langsford Road had the greatest reduction in delay when considering all of the five time-of-day periods studied together. A reduction in average delay was experienced at this intersection during each time period, and during three of these time periods the reduction was statistically significant at the 95 percent confidence level. The 12.5 second improvement experienced during the noon peak was significant at the 90 percent confidence level.

Table 12. Intersection Delay in the Northbound Direction

Intersection	Time period	Delay (sec) Before	After	Difference	Standard error	P–value
US 50 Ramps and Blue Parkway	AM Peak	13.4	12.5	–0.9	4.8	0.849
	AM Off Peak	12.5	7.0	**–5.5**	2.3	**0.024**
	Noon Peak	19.6	15.1	–4.6	5.8	0.441
	PM Peak	14.5	17.1	2.7	6.7	0.694
	Night Off Peak	11.1	14.7	3.6	5.2	0.497
Bayberry Lane	AM Peak	2.6	3.7	1.2	1.3	0.369
	AM Off Peak	5.8	3.1	–2.7	2.1	0.199
	Noon Peak	4.4	6.7	2.3	2.2	0.319
	PM Peak	11.6	6.4	–5.2	3.1	0.101
	Night Off Peak	2.5	0.9	–1.6	1.1	0.148
5th Street	AM Peak	2.7	4.7	2.0	1.9	0.308
	AM Off Peak	4.0	3.1	–0.9	1.5	0.546
	Noon Peak	5.7	3.9	–1.9	1.7	0.277
	PM Peak	10.1	3.5	–6.7	3.4	0.058
	Night Off Peak	1.9	0.4	–1.5	1.3	0.277
3rd Street	AM Peak	3.6	7.1	3.6	1.9	0.07
	AM Off Peak	5.1	4.6	–0.6	1.4	0.679
	Noon Peak	22.7	4.9	**–17.9**	4.6	**< .001**
	PM Peak	20.2	4.6	**–15.6**	5.0	**0.004**
	Night Off Peak	0.3	0.7	0.3	0.8	0.678
Langsford Road	AM Peak	7.7	7.5	–0.2	3.1	0.958
	AM Off Peak	10.8	3.5	**–7.3**	1.7	**< .001**
	Noon Peak	18.3	5.8	–12.5	7.2	0.09
	PM Peak	23.9	4.9	**–19.1**	7.0	**0.01**
	Night Off Peak	11.5	4.1	**–7.3**	3.2	**0.028**
Columbus Street	AM Peak	3.1	4.9	1.8	2.6	0.496
	AM Off Peak	3.8	3.6	–0.2	2.0	0.928
	Noon Peak	6.3	4.6	–1.7	3.0	0.585
	PM Peak	5.2	3.4	–1.8	2.3	0.441
	Night Off Peak	3.7	0.0	**–3.6**	1.4	**0.015**
Chipman Road	AM Peak	5.9	8.5	2.5	5.6	0.654
	AM Off Peak	2.7	1.8	–0.8	0.6	0.188
	Noon Peak	3.0	6.1	3.1	3.3	0.364
	PM Peak	1.8	4.3	2.5	3.5	0.485
	Night Off Peak	2.8	0.4	**–2.4**	1.1	**0.038**
Swann Drive	AM Peak	11.3	2.4	**–8.8**	1.9	**< .001**
	AM Off Peak	6.3	3.0	–3.3	2.2	0.149
	Noon Peak	9.8	2.8	–7.0	3.0	0.028
	PM Peak	4.6	5.4	0.8	2.8	0.767
	Night Off Peak	4.5	0.3	**–4.2**	1.7	**0.02**
Tudor Road	AM Peak	1.7	6.1	**4.4**	2.2	**0.049**
	AM Off Peak	2.7	6.6	3.8	2.2	0.092
	Noon Peak	20.2	5.1	**–15.1**	4.7	**0.003**
	PM Peak	6.5	5.4	–1.1	3.4	0.754
	Night Off Peak	12.5	4.3	**–8.3**	3.3	**0.016**
Mulberry Street	AM Peak	–0.8	–0.4	0.4	0.7	0.563
	AM Off Peak	–0.7	3.2	3.9	3.2	0.23
	Noon Peak	–0.2	1.1	1.2	2.3	0.59
	PM Peak	–0.9	–0.6	0.3	0.3	0.36
	Night Off Peak	–0.3	–2.1	–1.8	1.2	0.129

Table 13. Intersection Delay in the Southbound Direction

Intersection	Time period	Delay (sec) Before	After	Difference	Standard error	P–value
Mulberry Street	AM Peak	6.9	9.9	3.0	4.3	0.497
	AM Off Peak	5.1	18.1	**13.0**	5.2	**0.017**
	Noon Peak	23.8	17.9	–5.9	7.1	0.414
	PM Peak	10.1	27.4	**17.3**	7.6	**0.03**
	Night Off Peak	1.5	12.4	10.9	6.4	0.096
Tudor Road	AM Peak	27.2	8.5	**–18.7**	6.2	**0.005**
	AM Off Peak	31.1	6.2	**–25.0**	6.2	**< .001**
	Noon Peak	36.8	4.8	**–32.1**	3.6	**< .001**
	PM Peak	32.3	8.7	**–23.6**	7.4	**0.003**
	Night Off Peak	14.3	11.2	–3.0	5.0	0.545
Swann Drive	AM Peak	28.3	1.6	**–26.7**	0.8	**< .001**
	AM Off Peak	13.6	0.6	**–13.0**	3.1	**< .001**
	Noon Peak	22.3	1.2	**–21.1**	2.8	**< .001**
	PM Peak	4.4	1.3	**–3.1**	1.1	**0.008**
	Night Off Peak	3.1	0.6	–2.5	1.3	0.059
Chipman Road	AM Peak	19.2	2.1	**–17.1**	1.7	**< .001**
	AM Off Peak	16.0	1.1	**–14.9**	3.0	**< .001**
	Noon Peak	18.8	2.3	**–16.4**	3.6	**< .001**
	PM Peak	3.2	13.6	**10.3**	3.2	**0.003**
	Night Off Peak	3.5	2.2	–1.3	2.1	0.54
Columbus Street	AM Peak	2.1	2.0	–0.1	0.4	0.779
	AM Off Peak	13.3	2.0	**–11.4**	3.1	**< .001**
	Noon Peak	2.9	5.8	2.9	1.5	0.068
	PM Peak	3.1	5.9	2.8	1.6	0.084
	Night Off Peak	6.0	2.0	–4.0	3.0	0.184
Langsford Road	AM Peak	4.3	3.0	–1.3	1.2	0.298
	AM Off Peak	18.8	2.2	**–16.6**	2.9	**< .001**
	Noon Peak	22.6	6.0	**–16.6**	7.0	**0.024**
	PM Peak	50.9	6.3	**–44.6**	4.5	**< .001**
	Night Off Peak	6.3	1.6	–4.6	2.3	0.051
3rd Street	AM Peak	12.1	1.6	**–10.6**	3.1	**0.002**
	AM Off Peak	17.3	1.4	**–15.9**	4.5	**0.001**
	Noon Peak	27.4	5.2	**–22.2**	5.6	**< .001**
	PM Peak	3.6	8.7	5.1	2.8	0.075
	Night Off Peak	4.3	1.3	–3.0	1.9	0.122
5th Street	AM Peak	9.5	5.2	–4.2	2.7	0.123
	AM Off Peak	7.8	5.1	–2.7	2.4	0.261
	Noon Peak	3.7	7.1	3.4	3.5	0.334
	PM Peak	15.2	3.8	**–11.4**	3.2	**0.001**
	Night Off Peak	1.0	1.7	0.7	0.7	0.331
Bayberry Lane	AM Peak	18.4	2.9	**–15.5**	2.2	**< .001**
	AM Off Peak	21.0	2.3	**–18.7**	2.2	**< .001**
	Noon Peak	10.0	4.2	**–5.8**	2.7	**0.041**
	PM Peak	16.4	4.3	**–12.2**	3.8	**0.003**
	Night Off Peak	1.5	1.7	0.3	0.4	0.489
Blue Parkway and US 50 Ramps	AM Peak	25.3	10.4	**–14.9**	4.1	**< .001**
	AM Off Peak	33.6	8.3	**–25.2**	5.1	**< .001**
	Noon Peak	47.9	11.7	**–36.2**	5.3	**< .001**
	PM Peak	17.1	20.3	3.1	7.5	0.677
	Night Off Peak	16.7	15.3	–1.4	3.3	0.67

The following observations can be made for travel in the southbound direction based on the result in Table 13:

- Mulberry Street acts as a metering intersection, forming platoons of vehicles for progression through the corridor. This may explain the statistically significant increase in delay at Mulberry Street during the AM off-peak and PM-peak periods. An increase in average delay was also seen in the AM peak and night off peak periods, but the change was not significant.
- Other than at Mulberry Street, where delay increased, Columbus Street, Langsford Road, and 5th Street were the only intersections that did not show a statistically significant decrease in delay during the AM peak period. The decreases in delay seen at the remainder of the intersections ranged from about 10 seconds to nearly 27 seconds.
- In the morning off-peak period, significant reductions in average delay were realized at every intersection besides Mulberry and 5th Street (ranging from 11 to 25 second reductions in delay), with the greatest improvements seen at Tudor and the group of signals at the US 50 interchange area (US 50 ramps and Blue Parkway).
- During the noon peak, significant improvements were seen at every intersection except Mulberry Street, Columbus Street and 5th Street (ranging from 13- to 36-sec reductions in delay), and the largest of these were also seen at Tudor and the group of signals at the US 50 interchange area (US 50 ramps and Blue Parkway).
- In the PM peak, Mulberry Street and Chipman Road showed statistically significant increases in delay, while Tudor Road, Swann Drive, Langsford Road, 5th Street, and Bayberry Lane showed significant decreases. The greatest decrease was seen at Langsford Road, where average delay went from 51 seconds to only 6 seconds.
- In the night-time period, delay was very small on average in the before period, and while some decreases in delay were recorded, none of them were statistically significant.

The intersections where delay was significantly improved can be seen visually in the time-distance and speed-distance diagrams shown for the AM peak in Figures 5 and 6, presented previously in Section 3, and for all time periods in Appendix A.

Each of the segments analyzed for delay has a different length (as can be seen in Figures 10 and 11) due to varying signal spacing along the corridor. It is expected that delay over longer segments will be greater than delay over shorter segments, since delay is measured cumulatively over segment length. It is also expected that delay over the southernmost segment will be larger, since that segment incorporates three closely spaced signals. This expectation holds true in the data, both in terms of showing these areas to have the greatest initial delay, but also in showing that they had the potential for greatest improvements in delay.

4.3 Number of Stops Along Corridor

Data collected during the travel time runs were used to determine the number of times the test vehicle stopped along the corridor. The number of stops during a given travel time run was defined by the number of times the vehicle's speed fell to 3 mph or below. The number of stops that occurred for each travel time run were averaged over all the runs for a given time of day during the before period, and during the combined after periods. They were then compared, and the percent change from the beginning to the after periods is presented in Table 14.

Table 14. Average Number of Stops During Travel Time Runs by Direction and Time of Day

Direction	Study period	Average number of stops				
		AM peak	AM off peak	Noon peak	PM peak	Night off peak
NB	Before	0.6	0.8	1.8	1.5	1.6
	After	0.7	0.4	0.6	0.7	0.3
	Percent change	*17*	*–50*	*–69*	*–57*	*–81*
SB	Before	3.9	4.6	4.7	2.6	1.8
	After	0.2	0.3	0.6	1.2	1.3
	Percent change	*–95*	*–95*	*–88*	*–56*	*–31*

All times of day in both directions of travel saw a decrease in the average number of stops except the AM-peak period in the northbound direction. In that period, the vehicle averaged only 0.6 stops per run in the before period, and this increased to 0.7 stops on average in the after period, which is a minimal increase. In the before period, vehicles experienced less than two stops on average during each run in the northbound direction of travel. The number of stops was substantially higher in the southbound direction than in the northbound during the before period, reaching nearly five stops per run, on average, in the morning off peak and noon peak periods, and four stops per run in the AM-peak period. These three periods saw the greatest reduction in average stops per run, falling to an average of less than one stop per run. The average number of stops in the northbound and southbound directions during the combined after period for all times of day is similar, hovering between 0.2 stops and 1.3 stops per run. The number of times a driver is required to stop along the corridor is a measure that is easily perceived by the average driver and is likely something the driver is perhaps more aware of than travel time or average speed over the relatively short distance of the corridor. For these reasons, the reduction in number of stops shown in Table 14, especially in the southbound direction of travel, is probably the measure of system effectiveness that drivers notice and that most improves the quality of their trip.

4.4 Congestion

To measure the amount of time the average vehicle spends in congestion through the corridor, the speed profile of each travel time run was analyzed to determine the amount of time the vehicle spent equal to or below 20 mph and equal to or below 30 mph. The 20-mph speed corresponds to the Mid-America Regional Council's (MARC's) definition of congested speed, so this speed was chosen for consistency with transportation studies conducted by the regional MPO. The 30-mph speed was chosen by the research team to represent conditions less congested, but slow enough that a driver would clearly perceive the difference.

Table 15 presents the average time in seconds the vehicle spent at or below 20 mph and 30 mph for each travel time run by direction of travel and time of day. Average speed, which is computed as the total corridor distance divided by the total travel time (and therefore includes stopped and congested time), is also presented in the table. The average time spent at or below 3 mph is included in the table, and represents the average number of seconds the vehicle spent stopped or nearly stopped. Average values presented for the after period include the runs from both after period studies.

Table 15. Average Time Spent in Congestion by Direction of Travel and Time of Day

Direction	Time period	Test period	Average speed (mph)	Average time ≤ 3 mph (sec)	Average time ≤ 20 mph (sec)	Average time ≤ 30 mph (sec)
NB	AM peak	Before	37.6	7.6	21.9	40.8
		After	37.4	13.2	26.8	46.8
		Percent change	*–0.4*	*73.0*	*22.1*	*14.7*
	AM off peak	Before	37.5	7.0	20.8	42.8
		After	39.8	5.2	11.9	25.65
		Percent change	*6.0*	*–25.0*	*–42.8*	*–40.1*
	Noon peak	Before	30.4	53.4	76.1	100.5
		After	37.4	14.6	22.6	45.4
		Percent change	*23.2*	*–72.8*	*–70.2*	*–54.8*
	PM peak	Before	32.2	47.4	67.5	92.8
		After	37.5	13.0	25.4	47.5
		Percent change	*16.5*	*–72.5*	*–62.3*	*–48.8*
	Night off peak	Before	38.0	16.9	35.6	54.9
		After	44.1	1.6	7.8	16.6
		Percent change	*15.9*	*–90.2*	*–78.2*	*–69.9*
SB	AM peak	Before	27.3	59.3	113.9	158.3
		After	39.8	5.4	12.4	28.6
		Percent change	*45.8*	*–90.9*	*–89.1*	*–81.9*
	AM off peak	Before	25.5	82.2	138.6	188.1
		After	41.0	5.3	8.9	19.2
		Percent change	*61.0*	*–93.6*	*–93.6*	*–89.8*
	Noon peak	Before	23.8	104.7	161.9	204.7
		After	38.3	11.0	21.2	38.8
		Percent change	*60.9*	*–89.4*	*–86.9*	*–81.1*
	PM peak	Before	27.3	70.5	112.5	151.2
		After	34.8	15.8	40.2	73.0
		Percent change	*27.3*	*–77.5*	*–64.2*	*–51.7*
	Night off peak	Before	36.9	19.9	42.4	60.8
		After	40.0	10.8	24.8	38.8
		Percent change	*8.4*	*–45.7*	*–41.5*	*–36.1*

The table shows that for each time of day period in both directions of travel, the average speed increased, except during the AM peak in the northbound direction. The decrease in average speed during that time was less than 1 mph. The largest improvements were seen in the southbound direction in the AM off peak and noon peak, where the average speed increased by about 15 mph, or over 60 percent. Average speeds in the before period ranged from 23 mph to 38 mph, and in the after periods, the average speed ranged from 35 mph to 44 mph, nearly reaching free flow speed (45 mph).

The table also shows that except for the AM peak in the northbound direction, all times of day in both directions of travel showed a decrease in the amount of time spent at a stop as well as at the two levels of congested conditions. The biggest decreases were seen during the AM peak, morning off peak, and noon peak in the southbound direction of travel. In some of these instances, the time spent in congested conditions decreased by over 90 percent.

4.5 Fuel Consumption and Emissions

While typical drivers are less aware of the fuel their vehicle consumes or the emissions their vehicle produces over a short segment of roadway, these are important measures of the benefits that may be realized due to signal improvements along an arterial. The reduction in fuel consumption and emissions for one car on one trip is negligible, but when multiplied by the number of vehicles using the corridor each day, and the number of trips each vehicle may make in a year, these benefits quickly become substantial and thus important.

The percent change in average fuel consumption and average emissions between the before study period and the combined after study periods are shown in Table 16 for each time of day and direction of travel. The values shown represent the average savings in fuel and reduction in emissions for a single vehicle, so they are very small. It is also important to note that the calculations used for fuel consumption and emissions are estimated by the PC-Travel software used for the travel time study. The estimates are based on velocity and acceleration through the corridor, which are computed using the distance traveled over 1-second intervals. These estimates may not truly represent the amount of fuel consumed or emissions produced by the typical vehicle traveling through the study corridor (much more sophisticated techniques would need to be used to gather precise estimates), but they are valid measures for comparison of relative fuel consumption and emissions generated from one study to the next. In other words, the change in fuel consumption and emissions over the study corridor from the before to the after period is a more reliable measure of effectiveness than the actual quantities of fuel consumed and emissions produced estimated for each run.

In line with the pattern of results seen in the measures of effectiveness described in previous sections of this report, reductions in fuel consumption and emissions were seen during all time periods in both directions of travel except the AM peak in the northbound direction. Because emissions and fuel consumption increase when a vehicle accelerates, travel time runs that experience a greater number of stops show an increase in these measures. Periods where stops were greatly reduced show a decrease in these measures. The greatest reductions in average fuel consumption and emissions were seen in the AM peak, morning off peak, and noon peak in the southbound direction of travel.

Table 16. Average Fuel Consumption and Emissions Generated Per Travel Time Run by Time of Day and Direction of Travel

Direction	Time period	Test period	Average fuel consumption (gal)	Average HC (g)	Average CO (g)	Average NO_x (g)
NB	AM peak	Before	0.11	9.70	113.00	5.86
		After	0.12	10.30	117.85	6.38
		Percent change	*4.5*	*6.2*	*4.3*	*8.8*
	AM off peak	Before	0.11	10.50	122.60	6.61
		After	0.11	9.20	109.60	5.42
		Percent change	*0.0*	*–12.4*	*–10.6*	*–18.0*
	Noon peak	Before	0.12	12.00	132.10	7.30
		After	0.12	10.25	118.85	6.26
		Percent change	*–4.2*	*–14.6*	*–10.0*	*–14.2*
	PM peak	Before	0.12	11.60	130.70	7.00
		After	0.12	10.35	120.45	6.44
		Percent change	*–4.2*	*–10.8*	*–7.8*	*–8.1*
	Night off peak	Before	0.12	11.30	134.10	7.38
		After	0.11	8.90	112.45	5.41
		Percent change	*–8.3*	*–21.2*	*–16.1*	*–26.8*
SB	AM peak	Before	0.13	14.00	137.50	9.08
		After	0.11	8.30	97.80	4.55
		Percent change	*–19.2*	*–40.7*	*–28.9*	*–49.9*
	AM off peak	Before	0.13	14.10	137.50	8.80
		After	0.11	8.10	97.70	4.40
		Percent change	*–19.2*	*–42.6*	*–28.9*	*–50.0*
	Noon peak	Before	0.14	15.00	146.40	9.36
		After	0.11	9.25	108.35	5.40
		Percent change	*–21.4*	*–38.3*	*–26.0*	*–42.4*
	PM peak	Before	0.13	12.50	126.50	7.41
		After	0.11	10.85	118.70	6.70
		Percent change	*–15.4*	*–13.2*	*–6.2*	*–9.6*
	Night off peak	Before	0.12	9.50	104.10	5.63
		After	0.11	8.65	99.05	4.99
		Percent change	*–8.3*	*–8.9*	*–4.9*	*–11.5*

4.6 Minor-Street Delay

The HCM method of calculating approach delay at a signalized intersection was used to measure minor-street delay at four intersections (eight approaches) during the AM peak, AM off peak, and PM peak. The HCM method provides a measure of the average delay experienced by all vehicles at an approach during the study period, rather than the delay experienced by each individual vehicle. For this reason, a statistical analysis could not be performed for minor-street delay because only one data point is available at each intersection approach for each study period. However, each of these data points represents several vehicles, so differences in delay between study periods is meaningful for comparison.

Figure 12 shows average delay per vehicle measured at the eastbound and westbound approaches at Chipman Road during three time-of-day periods (AM peak, AM off-peak and PM peak) for each study period. Table 17 compares average delay per vehicle from the before period to the average of the values measured in the two after periods and shows the percent change from the before to the combined after periods.

A slight increase in delay was seen in the PM-peak period, while greater increases were seen in the AM and Off-peak periods. When examining changes in delay to southbound traffic at Chipman Road (shown in Table 13), the greatest decreases in delay were seen in the AM peak, morning off peak, and noon peak periods. (In the northbound direction, changes in delay at Chipman Road were not significant—except during the Night Off Peak, which was not studied for minor-street delay.) These results indicate that improvements realized by traffic on the main corridor came at the cost of increased delay to traffic on the minor approaches. Increase in average delay per vehicle on the minor approaches ranged from about 7 seconds to about 10 seconds during the AM peak and morning off peak periods. Average reduction in delay to southbound vehicles at Chipman Road during these periods was 17 and 15 seconds, respectively, with no significant changes seen in the northbound direction of travel. Considering the higher volumes on the major approaches and that the improvements on the major approaches were greater than the increased delay on the minor approaches, the results indicate that overall intersection delay decreased from the before period to the after periods.

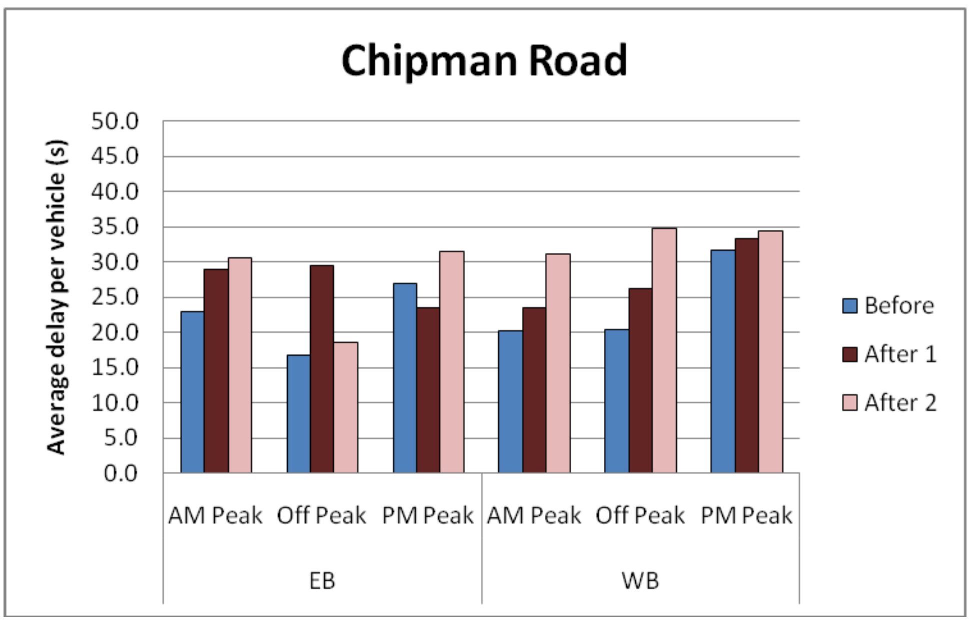


Figure 12. Minor-Street Delay per Vehicle at Chipman Road by Approach Direction, Study Period and Time of Day

Table 17. Change in Average Delay Per Vehicle at Chipman Road

Time of day	Approach direction	Average delay per vehicle at Chipman Road (sec)		
		AM peak	**AM off peak**	**PM peak**
EB	Before	23.0	16.8	27.0
	Average After	29.7	24.1	27.5
	Percent Change	*29.1*	*43.2*	*1.9*
WB	Before	20.2	20.3	31.7
	Average After	27.3	30.5	33.8
	Percent Change	*35.1*	*50.0*	*6.6*

Figure 13 and Table 18 provide similar information for the intersection at Columbus Street. At this intersection, average delay per vehicle decreased during the AM-peak period and increased during the AM off-peak period in both directions; however, it decreased for the eastbound approach while increasing for the westbound approach during the PM peak period. Tables 12 and 13 show that at Columbus Street, the only statistically significant change in delay for the vehicles on the major approach (during the three time-of-day periods when minor-street delay was measured) was an 11-second decrease that occurred in the southbound direction of travel during the AM off peak, which was the only time period when minor street delay increased for both approaches. Again, this illustrates the trade-off between major- and minor-street delays. However, it should be noted that during the AM-peak period, delay decreased for the minor approaches, while the delay for the major approaches did not significantly change.

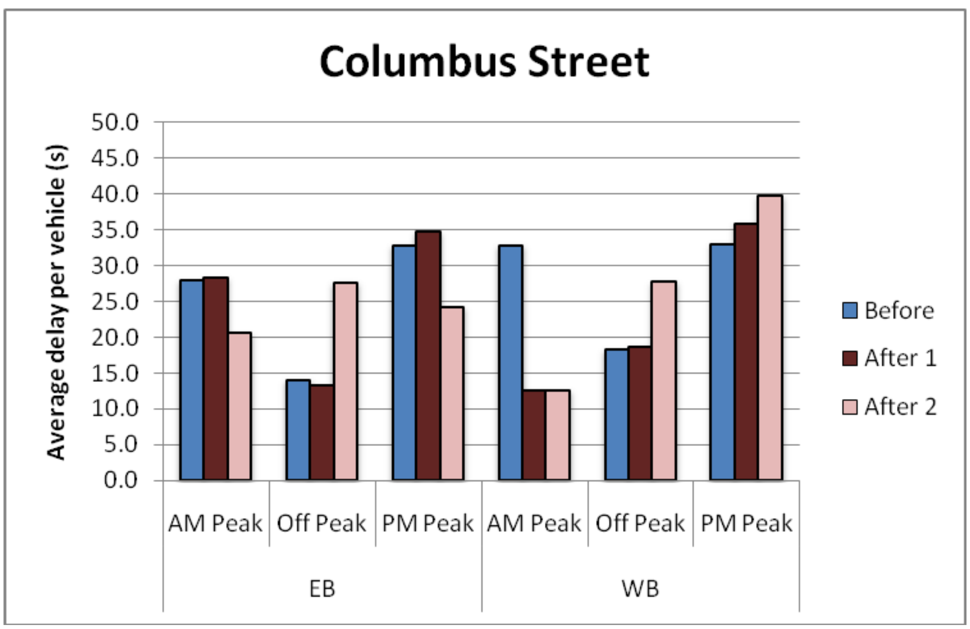


Figure 13. Minor-Street Delay Per Vehicle at Columbus Road by Approach Direction, Study Period, and Time of Day

Table 18. Change in Average Delay Per Vehicle at Columbus Street

Time of day	Approach direction	Average delay per vehicle at Columbus Street (sec)		
		AM peak	**AM off peak**	**PM peak**
EB	Before	28.0	14.1	32.9
	Average After	24.5	20.5	29.6
	Percent Change	*–12.5*	*45.4*	*–10.2*
WB	Before	32.9	18.3	33.1
	Average After	12.6	23.3	37.9
	Percent Change	*–61.7*	*27.0*	*14.4*

Results for the intersection at Langsford Road are shown in Figure 14 and Table 19. Here, changes in average delay per vehicle were very small; the difference between before and after periods was less than 2 seconds for each approach and time period except the westbound approach during the PM peak period when delay increased by nearly 18 seconds. Referring again to Tables 12 and 13, Langsford Road saw some of the biggest improvements in delay for the through movement on the major approaches, with the greatest decreases in delay seen during the PM peak (19 seconds in the northbound direction and 44 seconds in the southbound direction). While the westbound approach appears to have suffered during the PM peak as a result of this improvement, delay for minor streets during other times of day and for the eastbound approach appear to have suffered little despite improvements for mainline traffic.

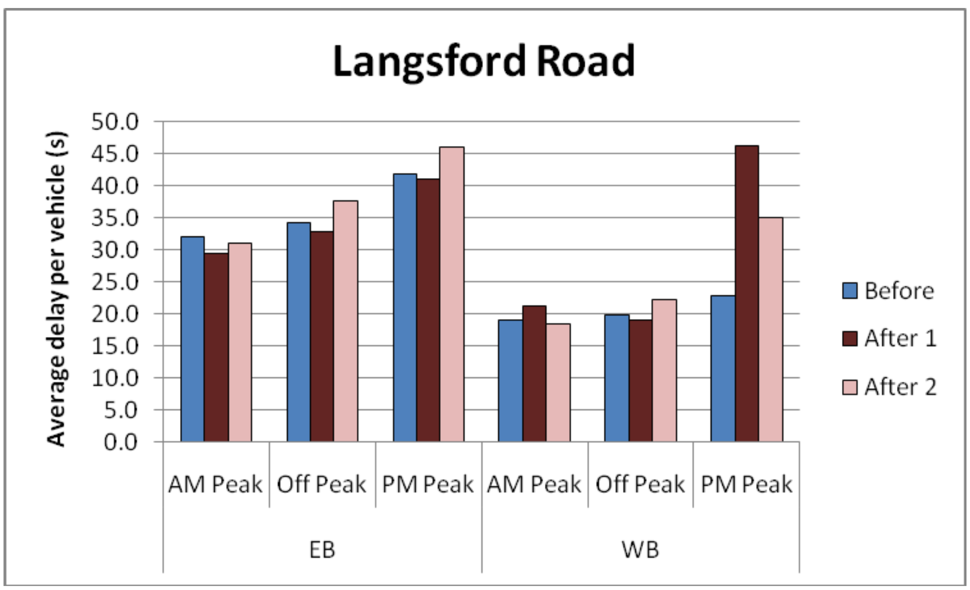


Figure 14. Minor-Street Delay Per Vehicle at Langsford Road by Approach Direction, Study Period, and Time of Day

Table 19. Change in Average Delay per Vehicle at Langsford Road

Time of day	Approach direction	Average delay per vehicle at Langsford Road (sec) AM peak	AM off peak	PM peak
EB	Before	32.0	34.3	41.9
	Average After	30.3	35.3	43.5
	Percent Change	*–5.3*	*2.8*	*3.8*
WB	Before	19.1	19.8	22.8
	Average After	19.9	20.7	40.7
	Percent Change	*3.9*	*4.5*	*78.3*

Figure 15 and Table 20 present the results of the minor-street delay study for the intersection at Tudor Road. At this intersection, the average delay per vehicle increased at both minor approaches during all three time periods except the eastbound approach during the PM peak period, which saw a decrease in average delay per vehicle of less than a second. Increases in delay ranged from about 3.5 seconds for the westbound approach during the morning off peak to about 12 seconds for the eastbound approach during the AM peak period. Looking back to Tables 12 and 13, a small, but statistically significant, increase in delay of about 4 seconds occurred at Tudor Road for northbound traffic during the AM peak, but for the southbound travelers at this intersection, delay decreased significantly during the AM peak, the AM off peak, noon peak, and the PM peak. At this intersection, results indicate that improvements to the mainline come at the expense of increased average delay for vehicles on the minor approaches. But again, in sec-per-vehicle, increases in delay for the minor street approaches are less than the improvements seen by the through-moving vehicles on the major approaches.

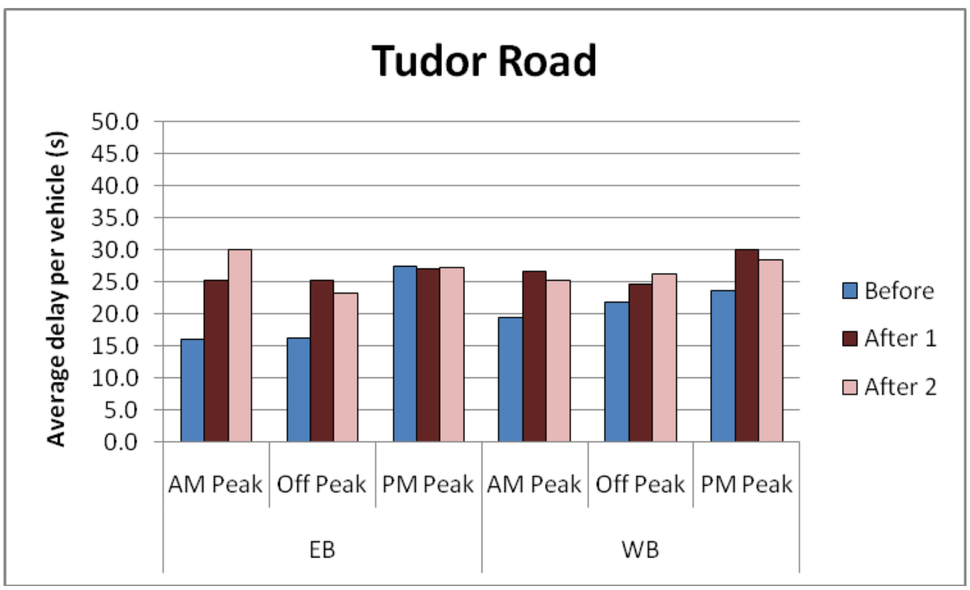


Figure 15. Minor-Street Delay Per Vehicle at Tudor Road by Approach Direction, Study Period, and Time of Day

Table 20. Change in Average Delay per Vehicle at Tudor Road

Time of day	Approach direction	Average delay per vehicle at Tudor Road		
		AM Peak	**AM Off Peak**	**PM Peak**
EB	Before	16.0	16.2	27.4
	Average After	27.7	24.3	27.2
	Percent Change	*73.1*	*50.0*	*–0.9*
WB	Before	19.5	21.9	23.7
	Average After	26.0	25.5	29.2
	Percent Change	*33.3*	*16.4*	*23.2*

The four intersections considered for the minor-street delay study were chosen because they provided a range of approach volumes, ranging from very low at Columbus Road, to the highest along the corridor at Tudor Road. Langsford Road and Chipman Road had moderate volumes that fell between those at Columbus and Tudor. An initial study question was whether the change in minor-street delay after the installation of the InSync system was correlated with approach volume. To explore this potential relationship, each approach volume for each 20-minute study period (including the before periods and both after periods) was plotted against the average delay per vehicle. This plot is shown in Figure 16 with no indication of a discernible relationship between these two variables. That is, the delay experienced per vehicle was not consistently greater or less for low volume intersections than for high volume intersections. It does show that delay during the PM peak was on average slightly higher than during the other two time periods, which is when mainline volumes are the highest.

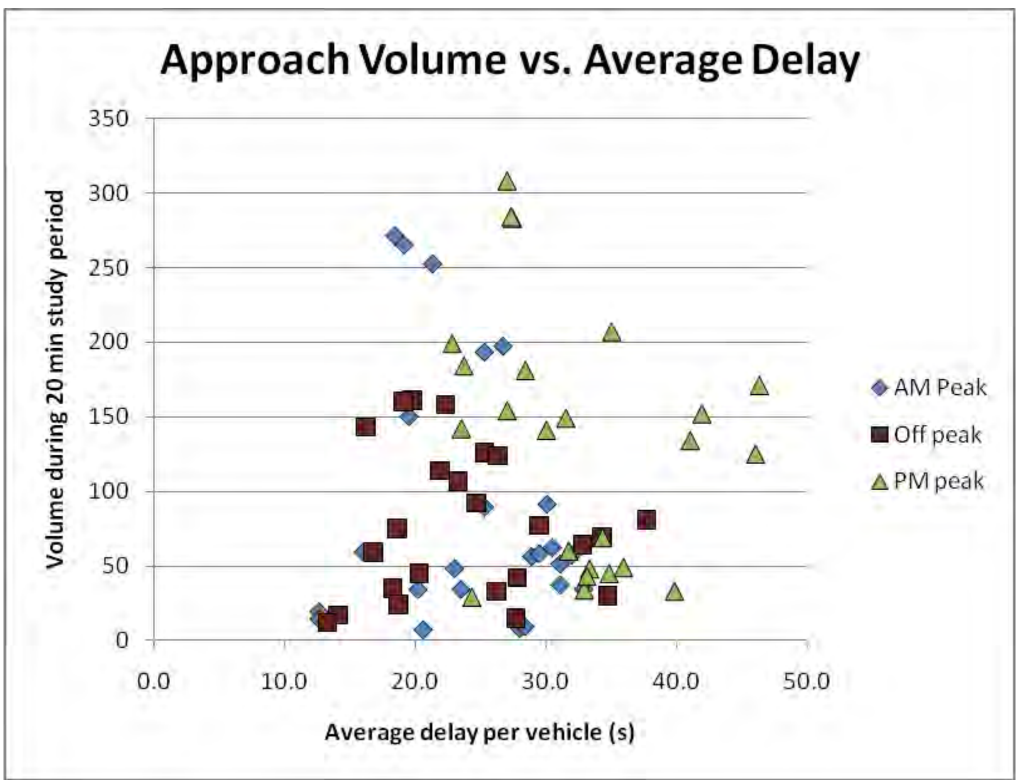


Figure 16. Approach Volume Versus Average Delay Per Vehicle for Minor-Street Approaches

The relationship between approach volume and the change in delay from the before periods to the after periods was also considered. This relationship is plotted in Figure 17, and again, no relationship between approach volume and change in average delay per vehicle is apparent. The plot does show that nearly all of the approaches experienced between a 1-second and 12-seconds increase in average delay across all of the time-of-day periods studied.

Overall, the minor-street delay study indicates that average delay per vehicle on the minor approaches increased after the installation of the InSync system. In general, the intersections and time periods that saw the greatest decrease in delay for the mainline through-moving vehicles also saw increases in minor-street delay. Also, in general, the increase in delay measured on the minor streets is less than the decrease in delay along MO 291. While the average delay to all drivers most likely decreased, considering the difference in approach volumes between the major and minor approaches, the appropriate distribution of delay between major and minor approaches should be determined by MoDOT traffic engineering staff, and will be decided in part by the threshold accepted by local drivers.

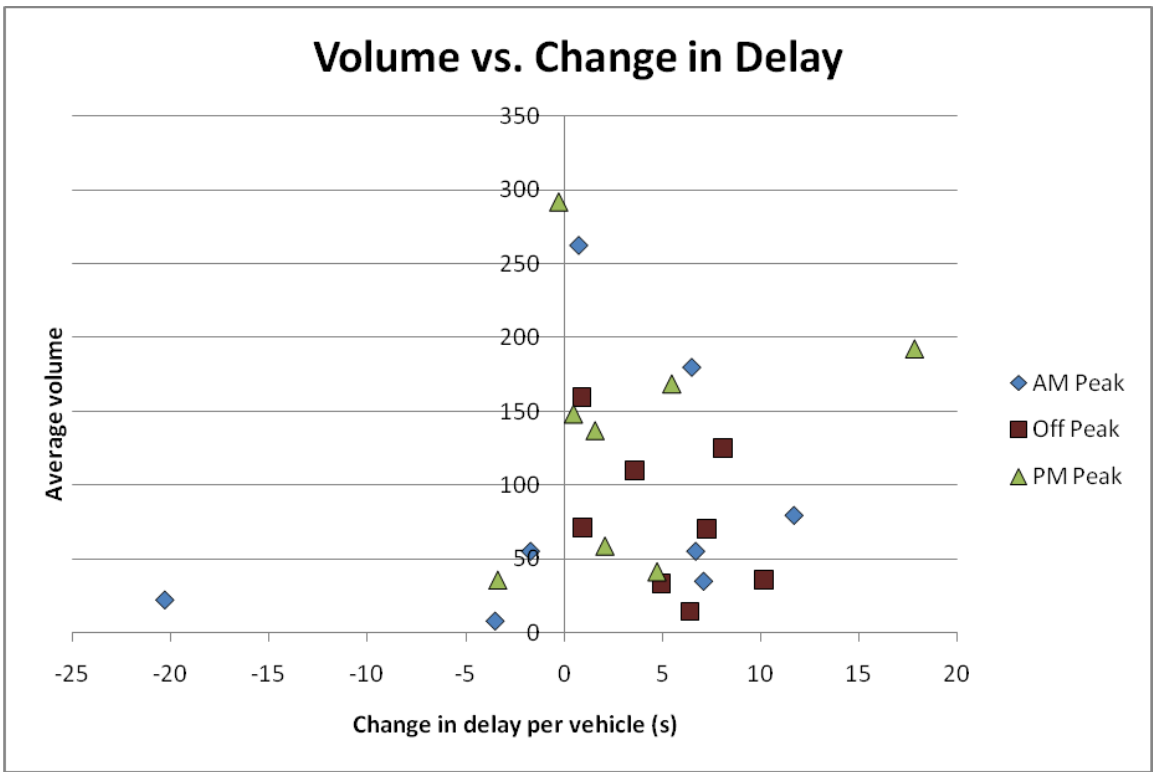


Figure 17. Approach Volume Versus Change in Average Delay Per Vehicle for Minor-Street Approaches

Section 5.
Agency Experience

5.1 MoDOT Experience

MoDOT and Rhythm Engineering completed the installation of the InSync system components at all intersections along the corridor in late March 2009. The transfer from the existing closed-loop intersection control to the new adaptive traffic signal system included a replacement of the controller at each intersection, and three small and outdated intersection cabinets (at Columbus, 3rd, and 5th Streets) were replaced with larger cabinets in order to better accept Rhythm Engineering cabinet hardware. A fiber communication connection between the intersections was installed by MoDOT signal shop staff to replace the twisted pair connection. These system improvements were not required for the InSync system, but rather improvements desired by MoDOT to update the corridor and prepare it for future projects. During the 7-day transition from the closed-loop system to the InSync adaptive system when the video detection was being replaced, the corridor ran on a pretimed signal plan. When this work was completed, Rhythm Engineering installed the cabinet hardware and MoDOT installed the cameras associated with the InSync system. By mid-April 2009, Rhythm Engineering had configured the system, observed its performance, and made the appropriate adjustments to the system to fix observed issues.

During the period between the completed installation of the system in late March and the beginning of the first after-period study in late April, the MoDOT signal shop reported receiving 17 malfunction reports in March and 8 malfunction reports in April. No calls were received during the study period (April 28 through May 7) and six calls were received in the month following the study period. By comparison, in the 3 months prior to the implementation of the system, a total of 10 calls were received (4 in December, 2 in January, and 4 in February). MoDOT reported that the majority of these calls were not actually malfunctions. Rather, drivers were responding to a violation of expectations, when phases were sometimes being called in a different order than they had been in the previous signal timing plan (that is, the green lights for each approach occurred in a new sequence than what drivers were accustomed to). In two cases, certain movements were not being called and MoDOT was forced to put those phases on recall so that those phases could not be “skipped” until Rhythm Engineering had a chance to address the malfunction.

Rhythm Engineering did not make changes to the system during the months between the first after-period study and second after-period study to ensure similar system operations for both evaluations. The MoDOT District 4 signal technicians reported an average of about three calls per month from drivers complaining of a skipped phase, a phase that was too short, or other detection-related problems in the months of June through October. MoDOT signal technicians indicated that the calls from customers complaining of a signal malfunction have increased since the InSync system has been implemented. They reported that, in general, the system is operating as programmed, but that occasionally the algorithm leads to skipped phases or green indications that are too short to completely clear queued traffic. Since each call must be investigated, the new system has led to a higher maintenance effort. Technicians also reported camera enclosures installed with the system have collected moisture, requiring maintenance to dry them out and replace the desiccant bag so they detect vehicles accurately, and the cameras have had to be reset on occasion. Moisture in detection camera enclosures is a common problem, regardless of video detection systems.

Rhythm Engineering provided training on the InSync system to MoDOT staff in early June. Those participating in the training reported that the system was presented as being easy to set up, but that the training did not involve field work. Staff at Rhythm Engineering installed and set up the timing algorithm for the system according to constraints and restrictions outlined by the MoDOT district traffic engineering staff. For example, if the intersection did not provide the geometry to allow opposing left turns to be served simultaneously, this constraint would be included in the system set-up. Because Rhythm Engineering performed the set-up, district traffic engineering staff could not report on how the installation of the system compares to the traditional closed-loop system formerly in place. MoDOT staff did report that the feature of the InSync system, which allows them to view the camera feeds along the corridor from their desk top, was beneficial and allowed them to identify issues from the office, saving them a trip to the field. They are unsure if the system will save them time and effort retiming the signals along the corridor, because it has not been in place long enough to make this determination.

The version of InSync in place on MO 291 does not have a feature to accommodate pedestrians within its signal timing algorithm. Instead, the intersections with pedestrian push buttons allow the signal to override the InSync algorithm and ignore the "tunnel" (similar to a greenband or throughband in a time-space diagram) so that the pedestrian phase will be activated. This system essentially handles pedestrians in the same way they were handled prior to the installation of the system, but it does disrupt the through traffic on MO 291 and causes interruptions to the tunnel. A newer version of InSync addresses pedestrian crossings within its algorithm. The level of pedestrian activity along the corridor was not measured as part of this study; therefore, the effects of the use of the pedestrian push buttons on the overall effectiveness of the system is unknown.

The version of InSync being used on MO 291 handles preemption from emergency vehicles in a similar manner to pedestrian calls. The preemption overrides the InSync algorithm for a short period of time and the tunnels are violated to allow the preemption to force a longer green time for the emergency vehicle.

5.2 Lee's Summit Police Department Experience

Just prior to the installation of the adaptive traffic signal system, the Lee's Summit Police Department had decided to begin targeted enforcement of the MO 291 corridor, citing a high number of right-angle crashes due to red-light running. The district traffic engineer at MoDOT agreed to provide several "tattle-tale" lights, which mount to the back of signal heads and indicate when the signal is red. This permits the officer to determine whether a vehicle has run a red light from the opposite side of the intersection, enabling him to follow and apprehend the offending driver without having to follow him through the red light. The “tattle-tale” lights were installed around the same time that the adaptive traffic signal system went into place. After some attempts at targeted enforcement along the corridor, officers indicated that such enforcement was no longer needed because red-light running was no longer occurring frequently enough to make the enforcement effective or efficient. The police department asked MoDOT to relocate the “tattle-tale” lights to intersections outside of the corridor. While the system’s effect on crash frequency was not evaluated as part of this project, the Lee’s Summit police captain responsible for traffic enforcement in the area believes that crashes along the corridor have decreased since the new system has been in place.

Section 6.
Conclusions and Recommendations

6.1 Conclusions

A comparison of data collected prior to system installation, and then 1 month and 5 months after system implementation indicated that the adaptive traffic signal system resulted in:

- shorter travel times
- reduced delay
- reduced time spent in congestions
- fewer stops along the corridor
- reduced fuel consumption
- reduced emissions

These results pertain to drivers traveling through the corridor in both directions during most times of day. It was also found that at no time during the study periods did any of these measures show significant increases when considering the entire corridor. The minor-street delay study indicated that some of the improvements along the mainline came at the cost of additional average delay per vehicle to drivers on the minor approaches, although the increase in delay was typically substantially less than the decreases in delay experienced by mainline drivers.

Highlighted conclusions from each study are presented below.

Travel Time Study

- The adaptive traffic signal system reduced travel times through the corridor by up to 39 percent, depending on the time of day and direction of travel.
- No statistically significant increase in travel time was found during any time period.
- The morning off-peak and noon-peak period in the southbound direction of travel experienced the greatest travel time improvements. During these periods, travel time was reduced by over 140 seconds (nearly 2.5 minutes).
- The system had the least impact on northbound travelers during the AM-peak and morning-off-peak periods, when no statistically significant difference in travel times was measured.
- The adaptive system significantly reduced travel time through the corridor in the northbound direction during three time-of-day periods:
  - Noon peak by 55 seconds (18 percent reduction)
  - PM peak by 44 seconds (15 percent)
  - Night off-peak by 34 seconds (14 percent)

- In the southbound direction of travel, statistically significant reductions in average travel time were seen in all five time-of-day periods:
  - AM-peak by 110 seconds (32 percent reduction)
  - AM off-peak by 144 seconds (39 percent)
  - Noon peak by 147 seconds (38 percent)
  - PM-peak by 74 seconds (22 percent)
  - Night off-peak by 19 seconds (8 percent)
- Travel times measured in the before period were substantially shorter during peak periods in the northbound direction (246 sec to 306 sec) than in the southbound direction (from 343 sec to 392 sec), indicating that the previous signal timing plan favored the northbound direction of travel, especially during the morning. This explains why greater improvements were seen in the southbound direction of travel.

Stops, Fuel Consumption, and Emissions Study

- The average number of stops through the corridor, fuel consumption, and emissions were reduced for every period where travel times were reduced.
- Changes in the average number of stops a vehicle made when traveling the length of the corridor ranged from an increase of 0.1 stop (17 percent) to a decrease of 4.3 stops (95 percent).
- Fuel consumption ranged from an increase of 0.01 gal per vehicle per trip (4.5 percent) to a decrease of 0.03 gal per vehicle per trip (21.4 percent).
- Change in emissions (measured for HC, CO, and NOx) ranged from an increase of 9 percent to a decrease of 50 percent, depending on time of day and direction of travel.
- Increases in each of these performance measures were only seen in the northbound direction of travel during the AM-peak period.

Average Speed and Time Spent in Congestion Study

- The change in average speed ranged from a decrease of 0.2 mph during the AM-peak in the northbound direction to an increase of 15.5 mph (from 25.5 mph to 41 mph) during the morning off-peak period in the southbound direction of travel.
- The decrease in time the average vehicle spent traveling at or below 20 mph ranged from 42 to 94 percent, excluding the AM-peak period in the northbound direction of travel.
- The decrease time the average vehicle spent traveling at or below 30 mph ranged from 36 percent to 90 percent, excluding the AM-peak period in the northbound direction of travel.

Minor-street Delay Study

- Changes in minor-street delay ranged from a decrease of 3 seconds to an increase of 12 seconds for most observation locations and time-of-day periods.
- Change in delay did not appear to be related to approach volume.
- In general, the intersections and time periods that saw the greatest increase in minor-street delay were those that saw a significant decrease in delay for the mainline through-moving vehicles.

Comparison of Volumes

- Traffic volume counts did not show a uniform increase or decrease in volume across times of day and locations.
- When volumes were summed across all sites through all the time-of-day study periods, the total-before period and after-period volumes were within 4 percent of one another.
- Traffic volumes between the before and after study periods were comparable.
- Reductions in travel time and delay do not appear to have resulted from any change in traffic volume through the corridor.

Comparison of Automated Camera Turning Movement Counts to Manual Counts

- Manual and automated counts produced similarly shaped graphs for each turning movement.
- Total volume by approach ranged from 5 percent to 53 percent higher when counted by the cameras then when counted manually.
- Discrepancies in individual turning movements ranged from –2 percent to 94 percent.
- The counts were closest for the northbound and southbound through movements, where differences were 2 percent or less.

6.2 Recommendations for Future Use of Adaptive Traffic Signal Systems by MoDOT

The InSync system was successful in reducing travel time and delay for motorists traveling through the MO 291 corridor. While a single study does not provide enough information to predict how the system will perform in other environments or compare the benefits of the InSync system to other adaptive traffic signal systems, some general observations may be helpful in determining locations where the adaptive system might provide benefits.

Locations with frequently or rapidly changing traffic demands are good candidates for the installation of an adaptive traffic signal system. Such locations may include:

- Developing areas with increasing traffic demand
- Arterials near stadiums, arenas and other venues where special events generate short periods of high volumes
- Corridors with short peak periods occurring when a nearby school is dismissed or a factory changes shifts
- Arterials that serve seasonal demands, such as routes near recreational areas or shopping centers
- Corridors with frequent incidents, whether due to crashes, work zones, or other occurrences that shift either capacity or demand
- Corridors with heavy directional traffic during the peak periods or signal spacing that makes two-way coordination difficult

Adaptive signal systems provide advantages over other systems in that they adjust timing plans based on real-time information. Because the InSync system has fewer restraints on the length or order of signal phases, it is more flexible in serving the demand on all approaches of an intersection. It does not have a transition period when adjusting the length or order of signal phases. In traditional closed-loop systems, the transition period may last longer than the period of increased demand, resulting in greater disruptions to the system and increased delay as the signal plan changes.

It is also suggested that an adaptive traffic signal system be further considered when traditional timing plans have been optimized and the agency still finds that drivers are experiencing excessive delays through the corridor. That is, low cost solutions such as traditional signal retiming should be implemented first. In some locations along the study corridor, travel times were well over 50 percent higher than the free-flow travel time. The InSync system was most effective during the time periods that had the greatest delay measured during the before-period study. Alternatively, the time periods when travel times were only 25 percent higher than the free-flow travel time in the before period experienced little or no statistically significant improvement after implementation of the InSync system. Because control delay will never be completely removed from a signalized corridor, there is a limit to the possible reduction in delay that can be realized. For this reason, it is recommended that an adaptive traffic signal system be considered when corridor travel times are 50 percent or more higher than the free flow travel time (i.e., the hypothetical travel time for a vehicle traveling at the posted speed limit through the corridor when all signals are green).

6.3 Recommendations for Future Research

Benefit-Cost Evaluation

A benefit-cost evaluation could be conducted to determine the economic benefits of the system in terms of fuel savings and time savings. Because this study only evaluated the system over five hours of the day, a cost-benefit would need to gather information for additional times of day or make assumptions about differences between the performance of the adaptive system and the previous system during these other times. Knowledge of the signal plans in place prior to the installation of the InSync system and a consideration of the traffic volumes throughout the day could be used by MoDOT to make assumptions about the expected changes to performance measures during the times of day that were not measured in this study. A full benefit-cost study should also consider the effects of the system on vehicles making turning movements and those entering from the minor approaches. Increased delay and number of stops at minor-street approaches would result in increased travel time, fuel consumption and emissions for these drivers, negating some of the benefits experienced by through drivers on the mainline.

Safety Analysis

A safety study is recommended to measure the effect of the adaptive traffic signal system on the frequency and type of crashes experienced along the corridor. Rear-end crashes typically make up a high percentage of total crashes at intersections, and it would be expected that when drivers encounter fewer red lights as they travel through the corridor, there will be fewer read-end crashes. Right-angle crashes are often severe crashes that can occur when drivers run red lights. It would be expected that when drivers face fewer red lights, fewer crashes related to red-light running will occur. Additionally, reducing delays and stops along the corridor may reduce driver frustration and reduce crashes related to aggressive driving.

Effect of the Adaptive Traffic Signal System on Pedestrians

The version of the InSync system in place on MO 291 does not accommodate pedestrians in its timing algorithm. Instead, at the signals where pedestrian push buttons are present, a pedestrian call overrides the algorithm and uses timing parameters defined in the controller to ensure sufficient crossing time. This may cause the “tunnel,” which is similar to a greenband or throughband, to be interrupted for a brief period, causing disruption to the approaching platoon of vehicles and causing additional delay for those vehicles. Pedestrian volumes are low along the MO 291 corridor, but they are present. A study of pedestrian volumes and frequency of push button use may help assess how the presence of pedestrians can affect system performance, and how the system affects pedestrian delay and crossing behavior.

Long-Term Benefits of the Adaptive Traffic Signal System

One of the advertised benefits of adaptive traffic signal systems is that regular signal retiming is no longer needed. Most agencies observe and retime signals according to a schedule, often every 2 to 3 years, depending on how conditions have changed. Because the InSync system is designed to automatically adjust to changing conditions, it is suggested that savings may be realized by eliminating the staff time needed to perform these evaluations and update timing plans. To determine the degree to which this claim is valid, the system could be reevaluated at the next scheduled corridor observation and the measures of effectiveness compared both to those presented in this report and to agency-defined acceptable levels. If it is determined that the system is still meeting expectations, a cost-savings can be calculated. The longer the system functions successfully without major changes to the algorithm, the greater the savings will be.

Section 7. References

1. “What Have We Learned About Intelligent Transportation Systems?” Federal Highway Administration. December 2000. http://www.itsdocs.fhwa.dot.gov//JPODOCS/REPTS_TE//13316.pdf.
2. Gomes, G. and A. Skabardonis. “Effectiveness of Adaptive Traffic Control for Arterial Signal Management.” California Partners for Advanced Transit and Highways (PATH). March, 2009.
3. Federal Highway Administration. Arterial Management Program website. http://ops.fhwa.dot.gov/acs_lite/development.htm.
4. J.M. Peters, J. McCoy, and R.L. Bertini. “Evaluating an Adaptive Signal Control System in Gresham.” Compendium of Technical Papers, Institute of Transportation Engineers, District 6 Annual Meeting, July 15-18, 2007 http://www.its.pdx.edu/upload_docs/1248894238mPTJ0AxnYW.pdf.
5. Martin, P. T. and A. Stevanovic. “Adaptive Signal Control V—SCATS Evaluation in Park City, UT.” Mountain Plains Consortium. July 2008. http://www.mountain-plains.org/pubs/pdf/MPC08-200.pdf.
6. Banerjee, F. T. “Preliminary Evaluation Study of Adaptive Traffic Control System (ATCS).” City of Los Angeles Department of Transportation. July 2001. Summary presented on Research and Innovative Technology (RITA) website. http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/CA4E16B4E7167BCF8525725F0073EBF3.
7. Eghtedari, A. G.,“Measuring Benefits of Adaptive Traffic Signal Control: Case Study of Mill Plain Boulevard, Vancouver, Washington.” Presented at the 85th annual meeting of the Transportation Research Board, January 2006.
8. “Crash Benefits of SCATS Control System.” Transportation Research Board. Research in Progress website. http://rip.trb.org/browse/dproject.asp?n=22140.
9. Transportation Research Board. *Highway Capacity Manual*. Washington, D.C., 2000.

Appendix A

Time-Space Diagrams and Speed-Distance Diagrams for Travel Time Runs

Figures A-1 through A-10 presented here show data collected for the travel time runs for each direction of travel and each of the five time-of-day periods studied. Travel times runs from the before and the two after periods are presented in each figure. In the upper graph in these figures, the slope of the line represents vehicle speed. When the vehicle slows, the steepness of the line increases because more time passes as the vehicle moves from one point along the corridor to another. Vertical jumps in the line indicate that the vehicle had to slow or stop at an intersection. Lines that are smooth with few jumps indicate that the vehicle did not have to slow or stop often. The lower graph in these figures shows the study vehicle's speed as it moves along the corridor. Where the lines dip, the speed is decreasing. The blue horizontal line represents a constant speed of 45 mph, the posted speed limit (assumed to be the free flow speed). A car experiencing no delay and traveling at the posted speed would have a speed-distance diagram along this blue line.

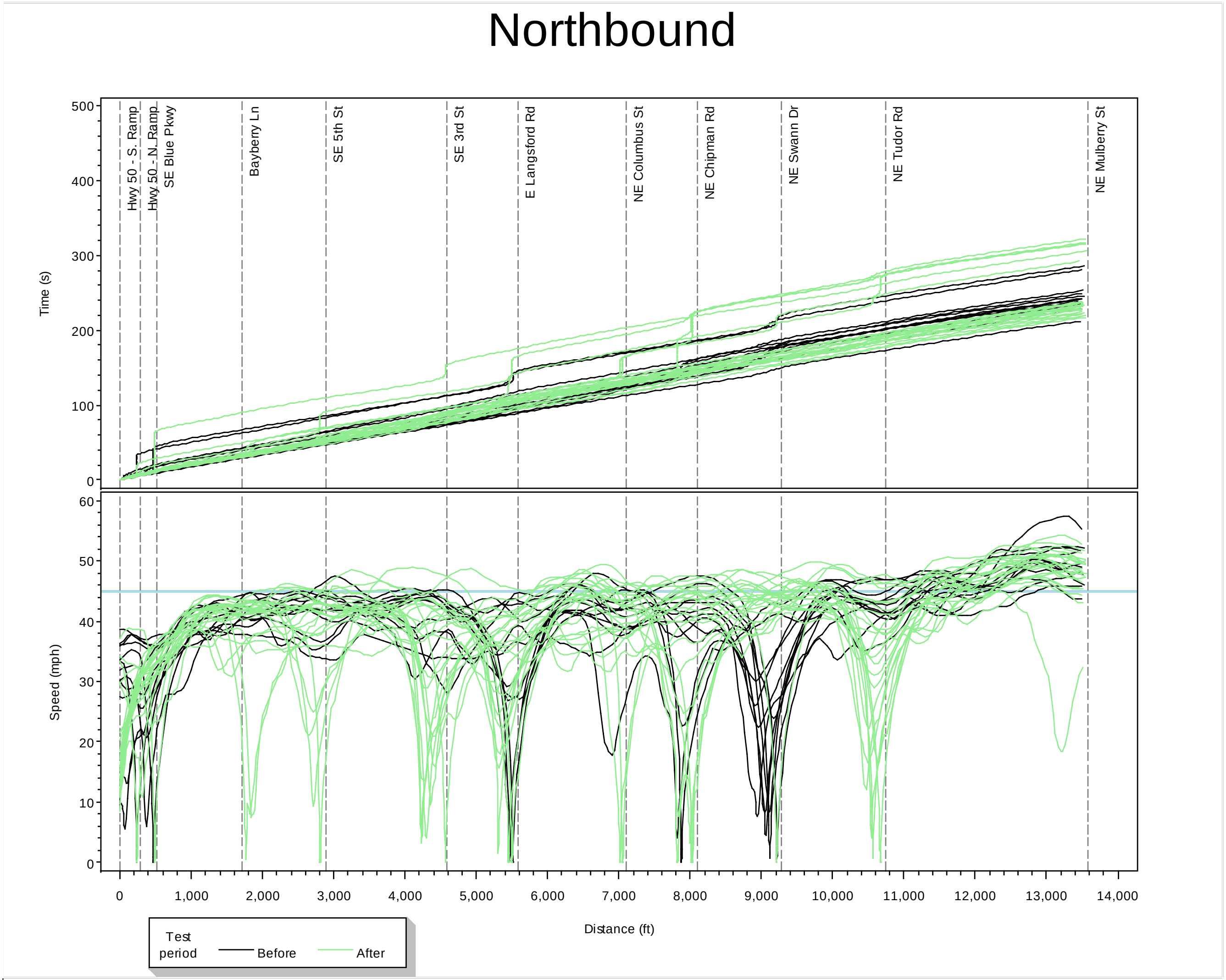


Figure A-1. Time-Distance and Speed-Distance Diagrams for Runs in the Northbound Direction During the AM Peak Period

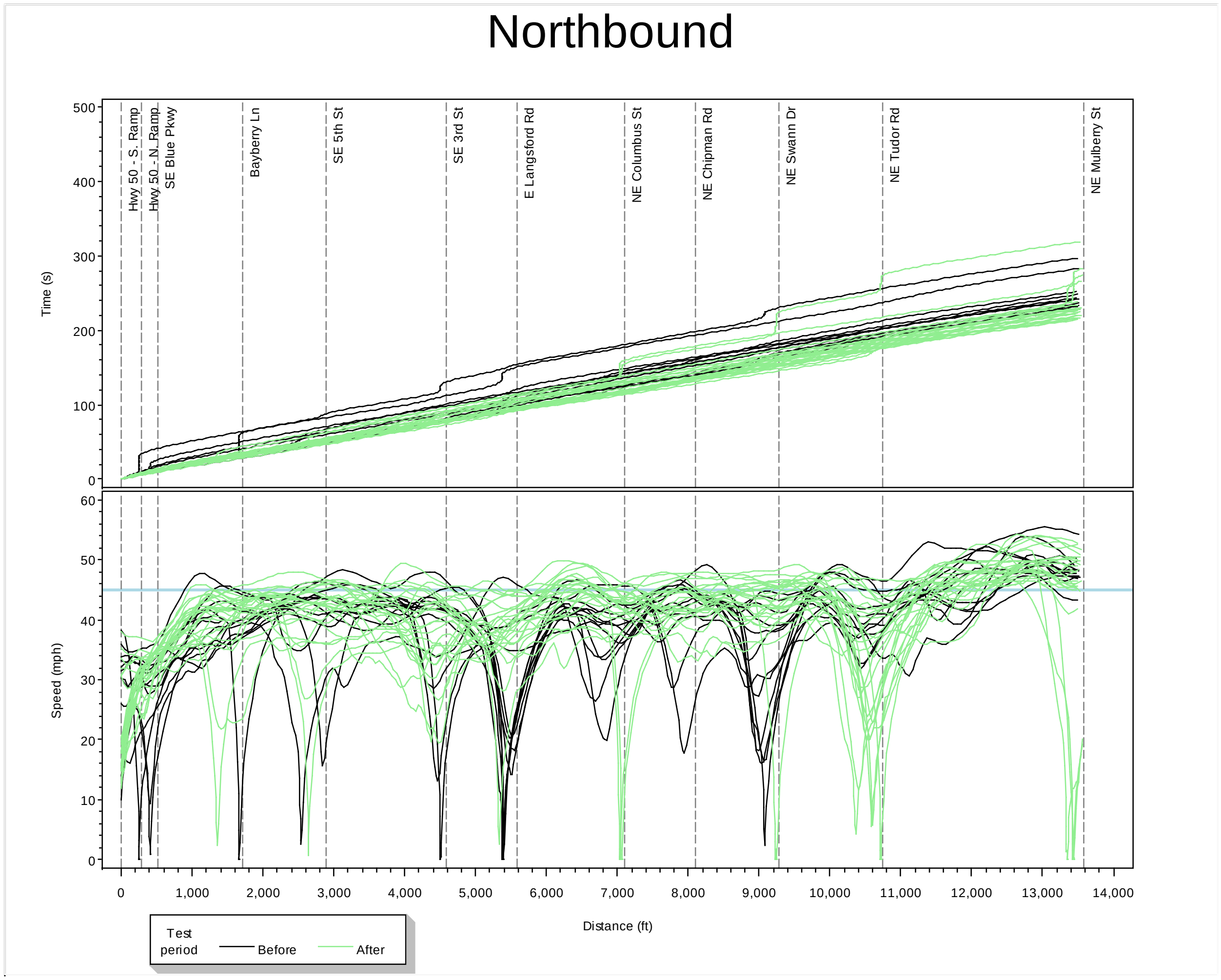


Figure A-2. Time-Distance and Speed-Distance Diagrams for Runs in the Northbound Direction During the Morning Off-Peak Period

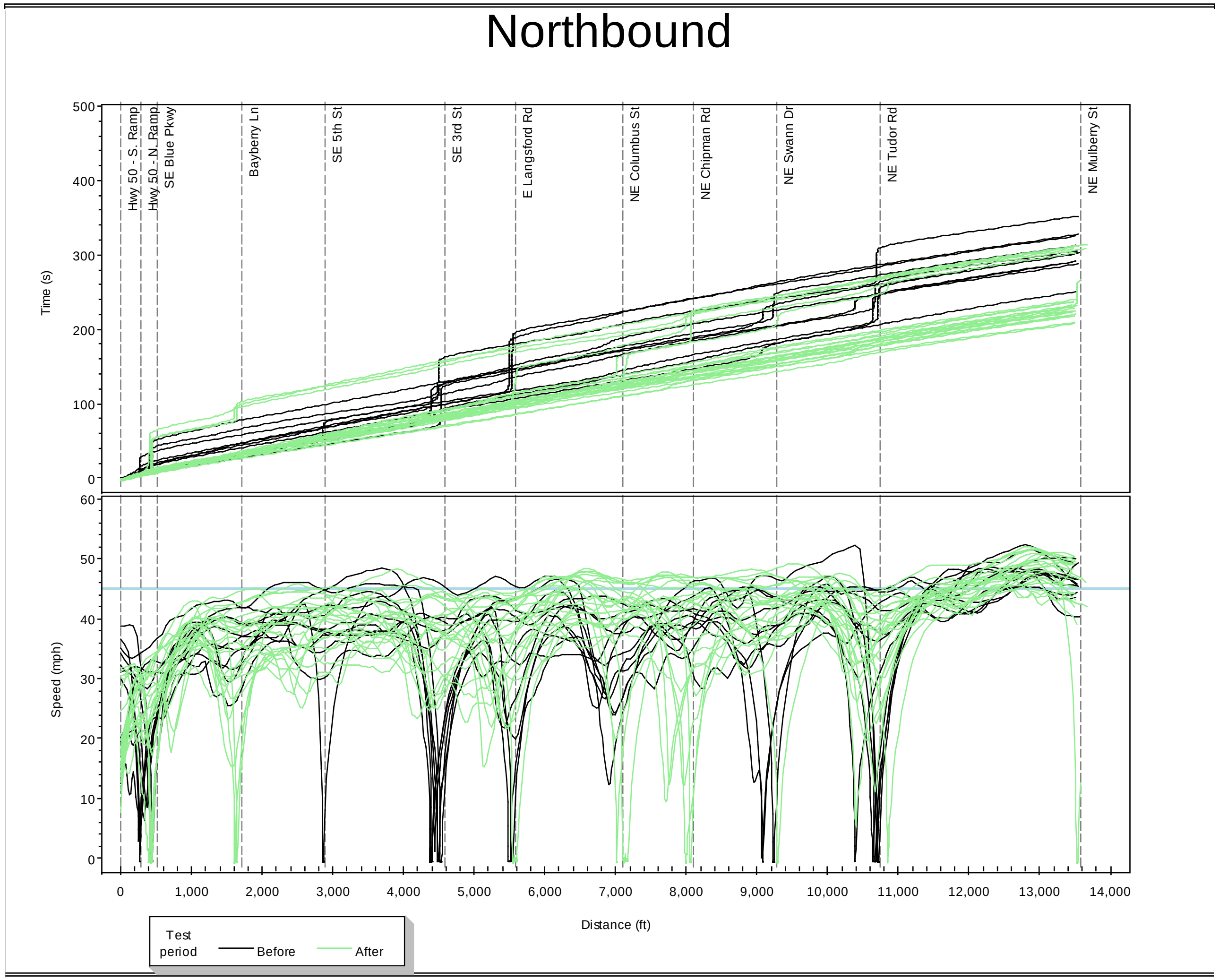


Figure A-3. Time-Distance and Speed-Distance Diagrams for Runs in the Northbound Direction During the Noon Peak Period

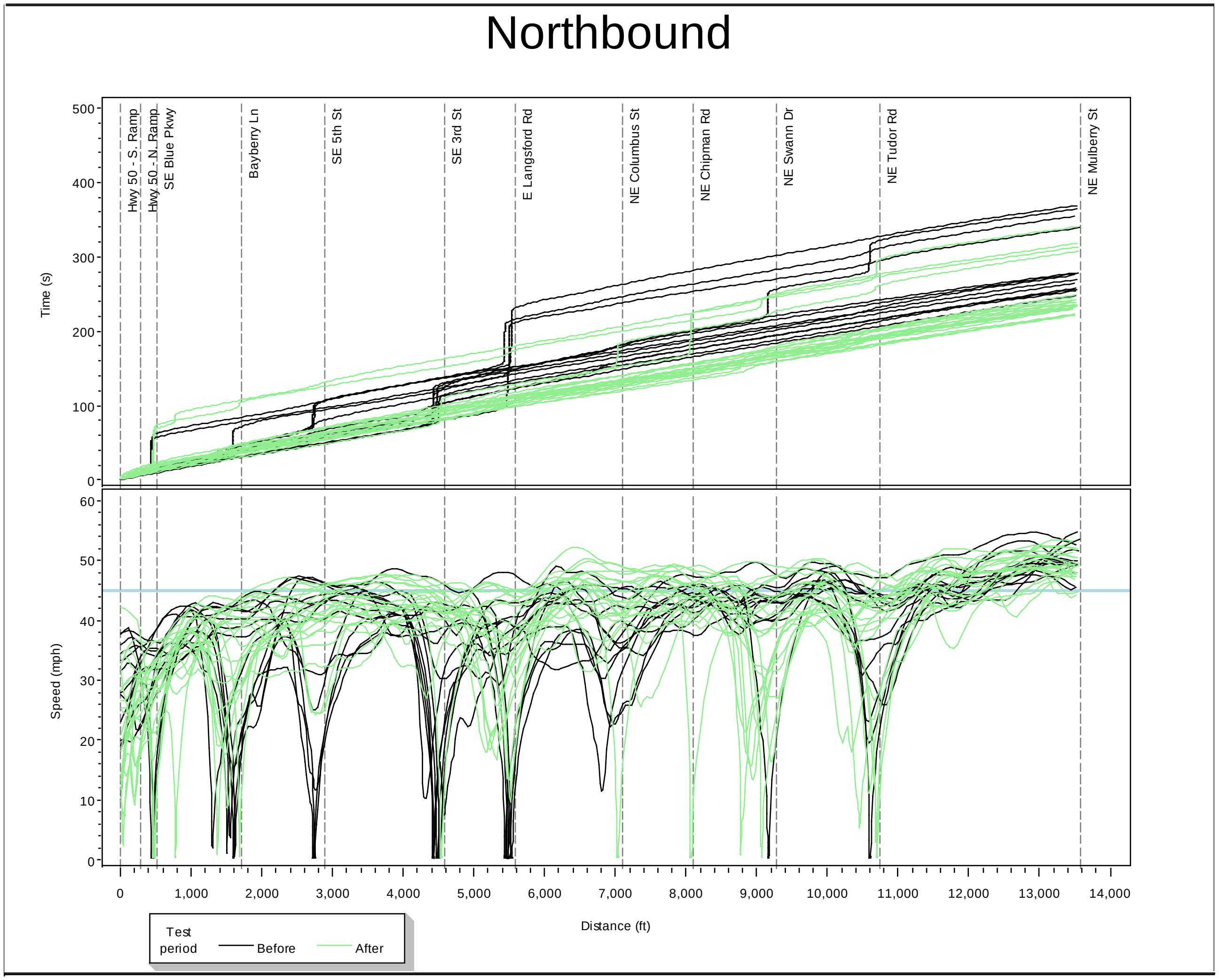


Figure A-4. Time-Distance and Speed-Distance Diagrams for Runs in the Northbound Direction During the PM Peak Period

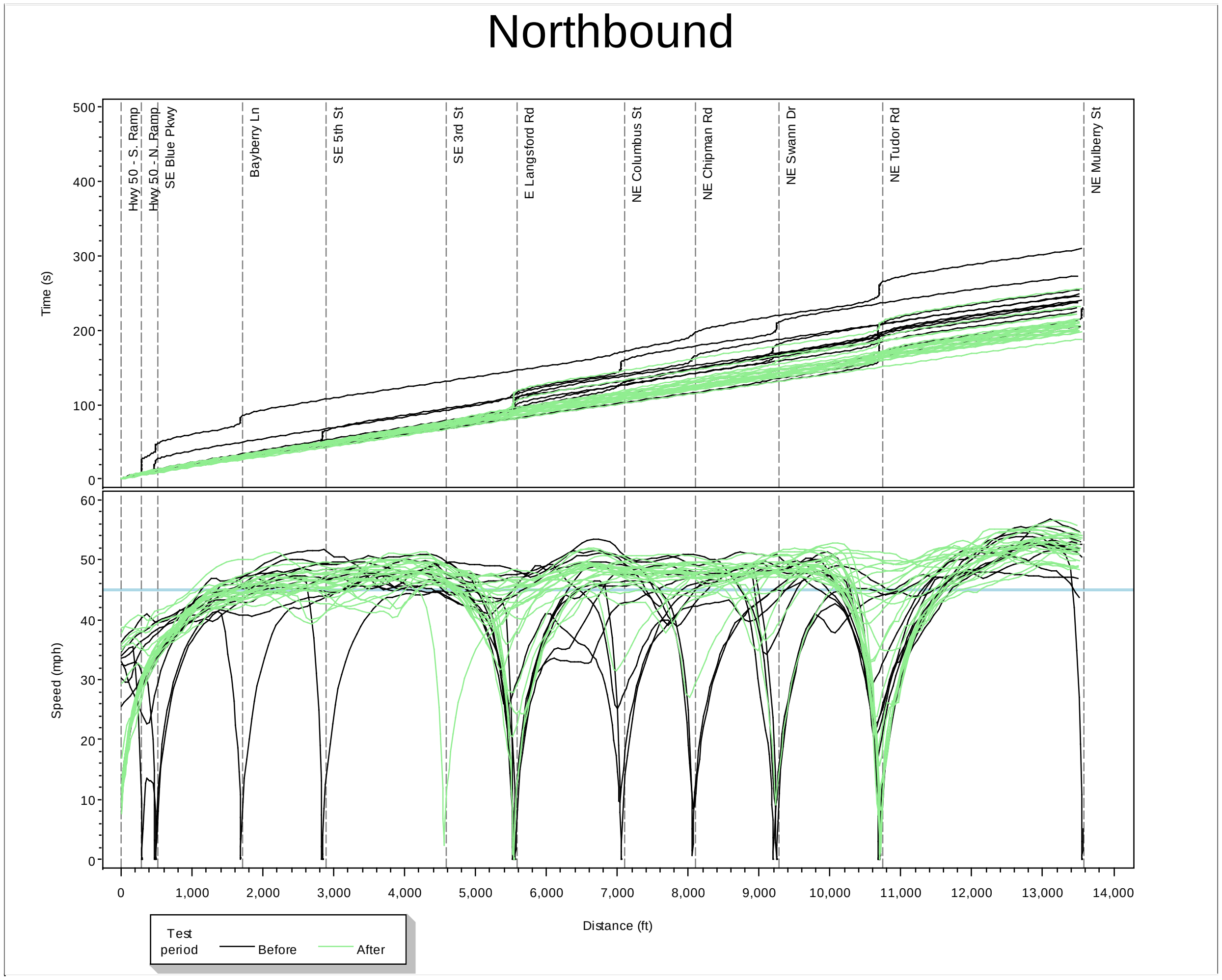


Figure A-5. Time-Distance and Speed-Distance Diagrams for Runs in the Northbound Direction During the Night Off-Peak Period

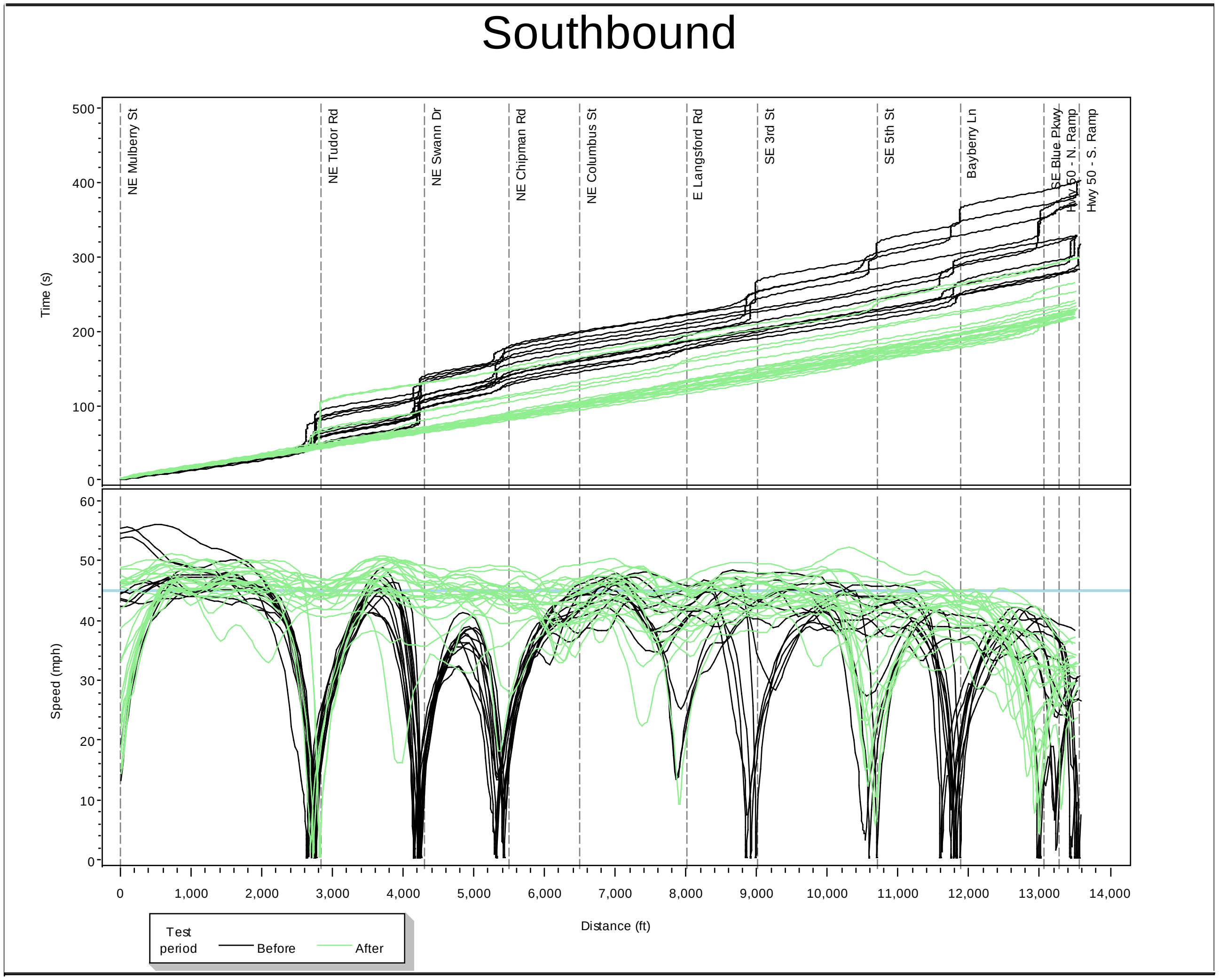


Figure A-6. Time-Distance and Speed-Distance Diagrams for Runs in the Southbound Direction During the AM Peak Period

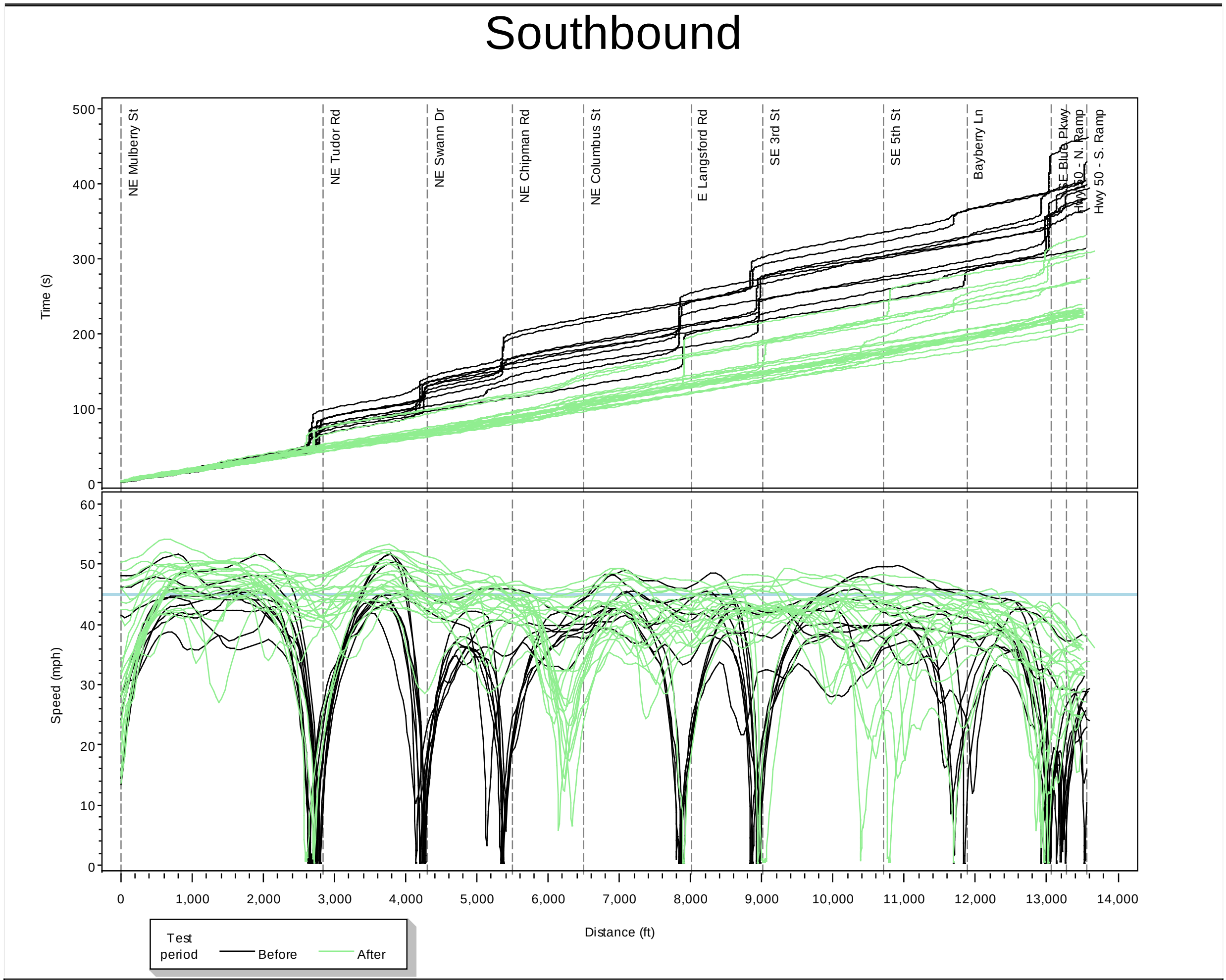


Figure A-7. Time-Distance and Speed-Distance Diagrams for Runs in the Southbound Direction During the Morning Off-Peak Period

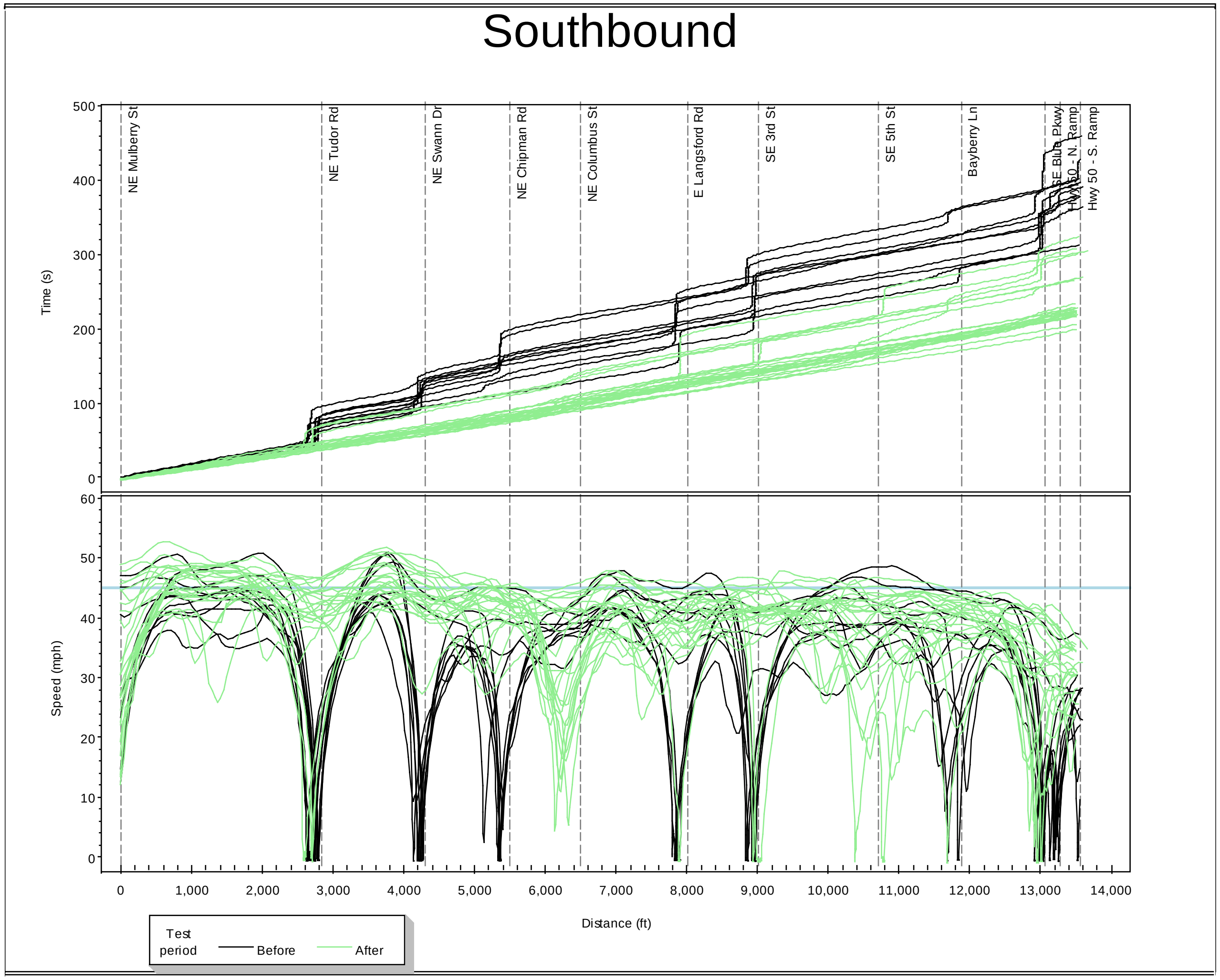


Figure A-8. Time-Distance and Speed-Distance Diagrams for Runs in the Southbound Direction During the Noon Peak Period

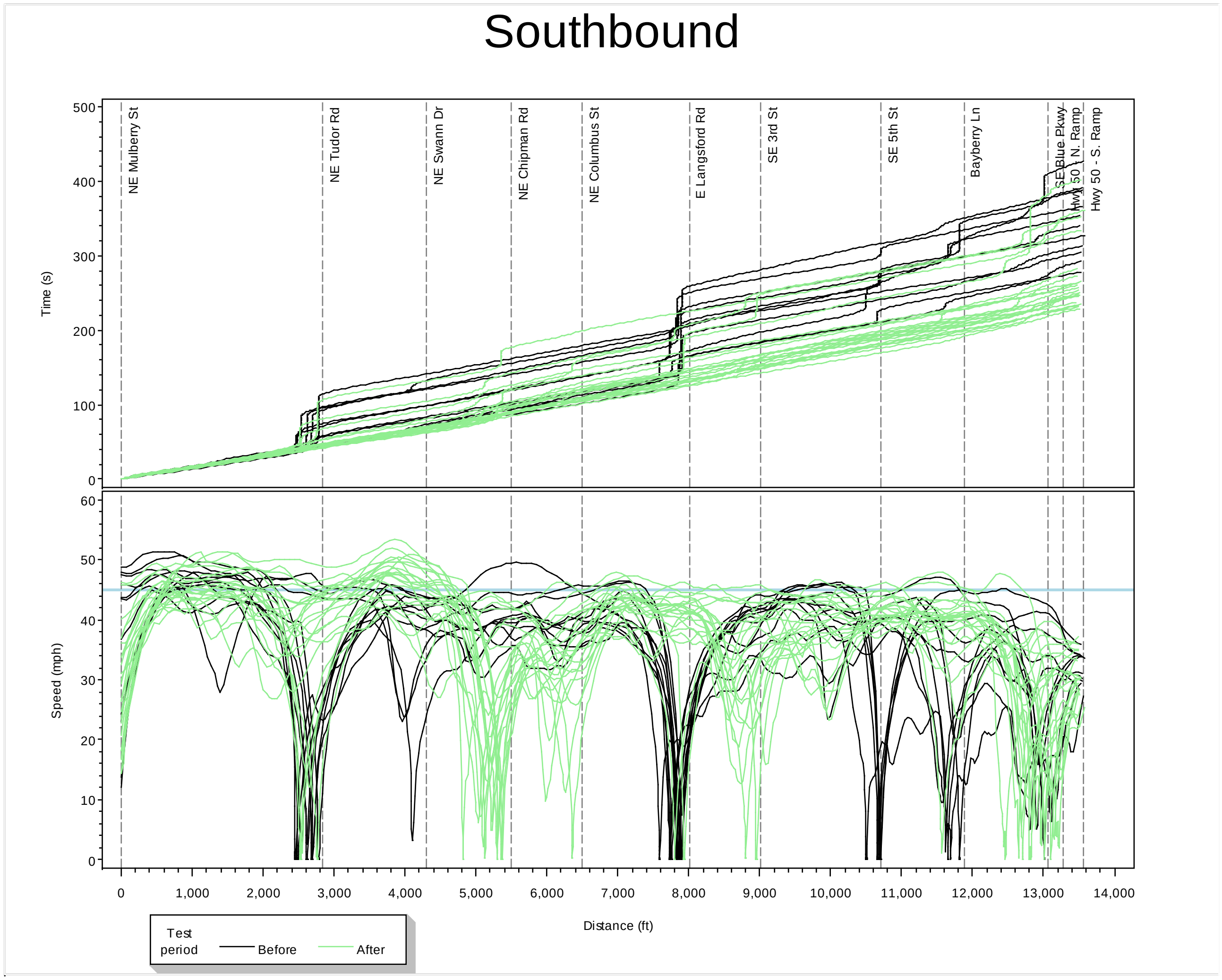


Figure A-9. Time-Distance and Speed-Distance Diagrams for Runs in the Southbound Direction During the PM Peak Period

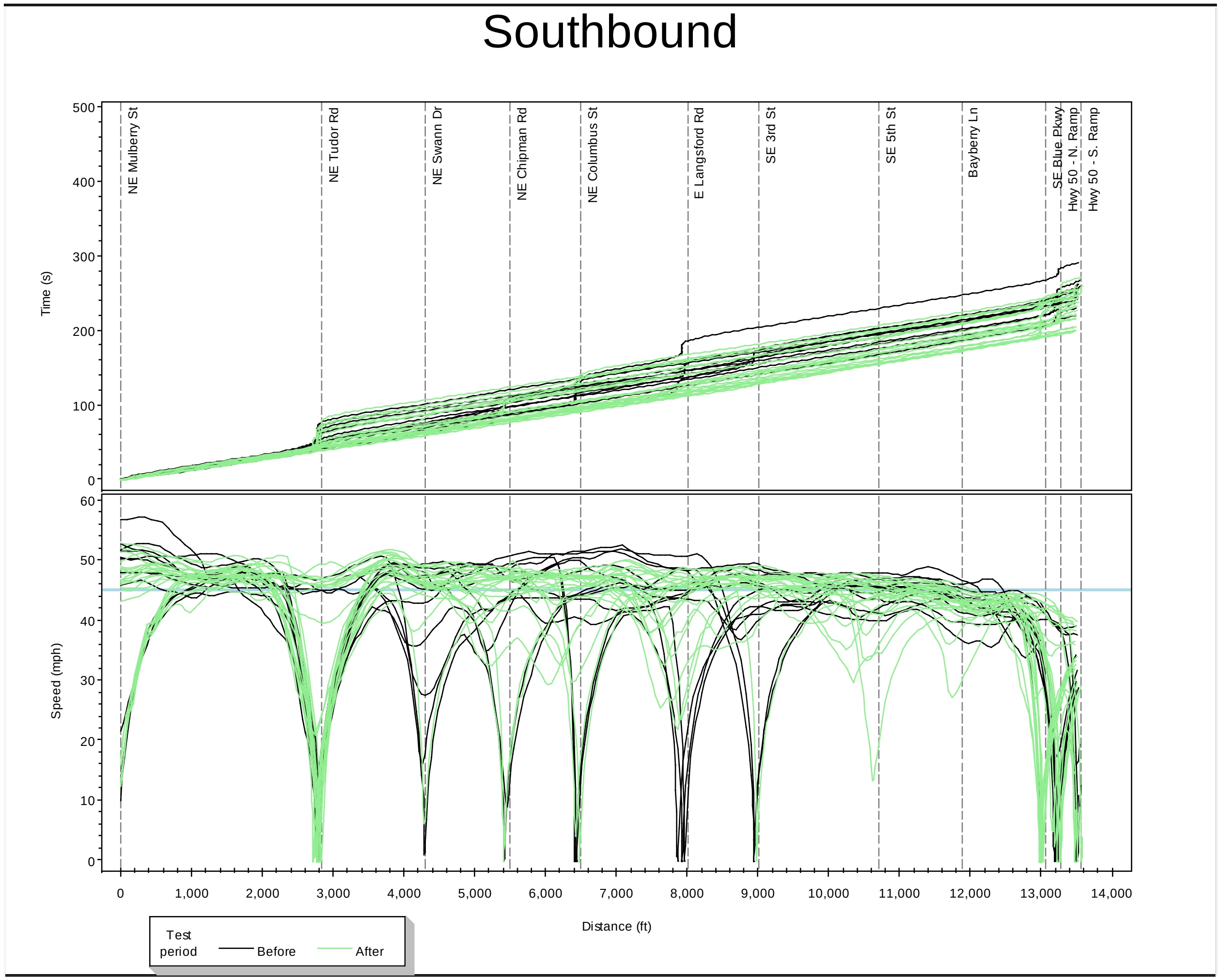


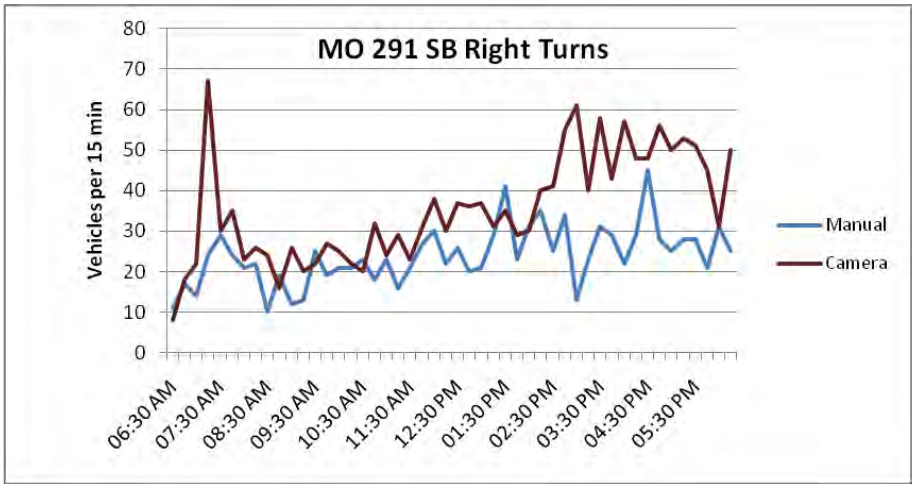
Figure A-10. Time-Distance and Speed-Distance Diagrams for Runs in the Southbound Direction During the Night Off-Peak Period

Appendix B

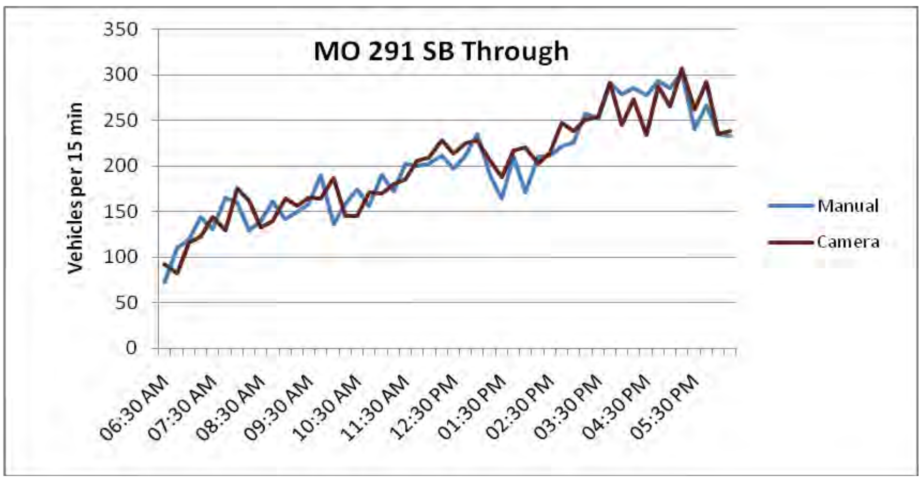
12-Hour Turning Movement Count Comparisons

Figures B-1 through B-4 present plots of the 15-minute turning movement volumes collected both by the detection cameras used by the InSync system and by a manual count. The counts were recorded from 6:30 am to 6:30 pm on Thursday, August 20, 2009. Total counts are also presented. Each figure shows a plot for right-turning vehicles, left-turning vehicles, and through vehicles.

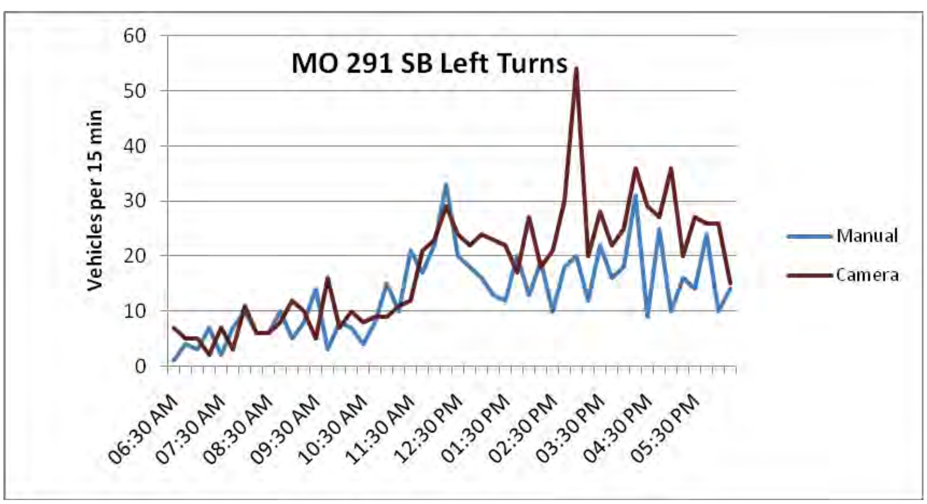
Table B-1 presents the 15-minute turning movement volumes by counting method.



12-hr totals	
Manual	Camera
1145	1700

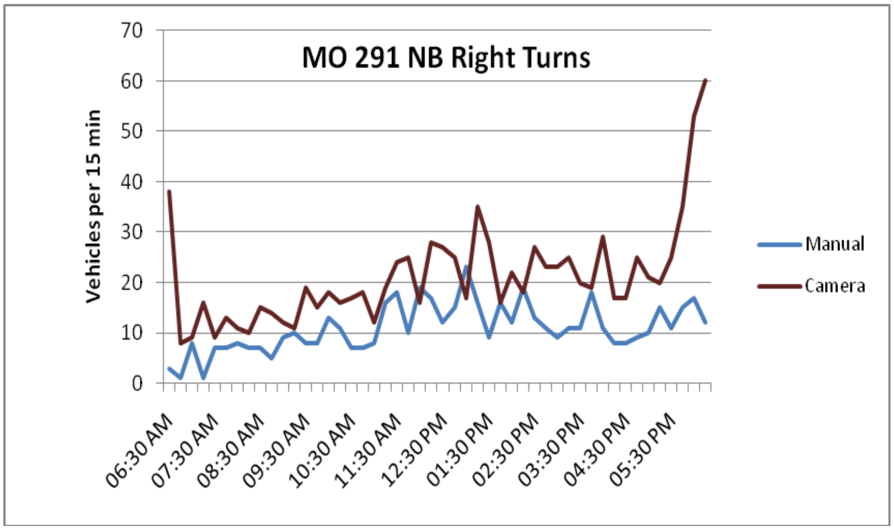


12-hr totals	
Manual	Camera
9529	9614

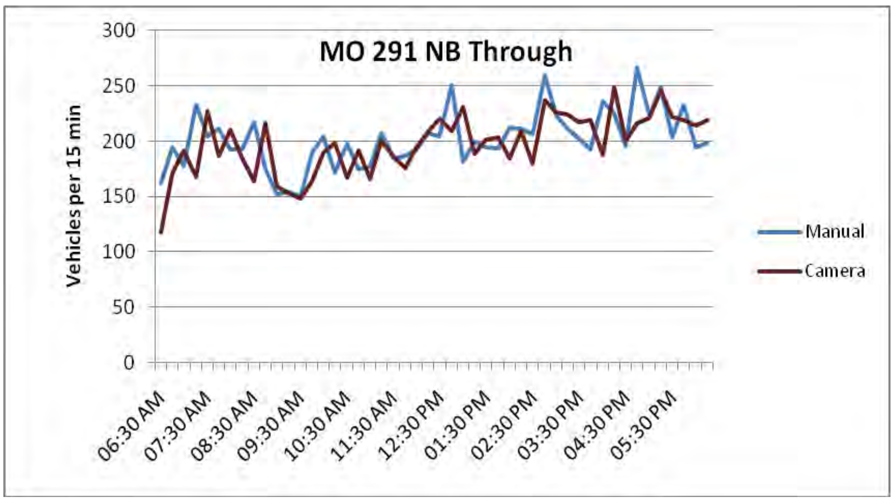


12-hr totals	
Manual	Camera
631	861

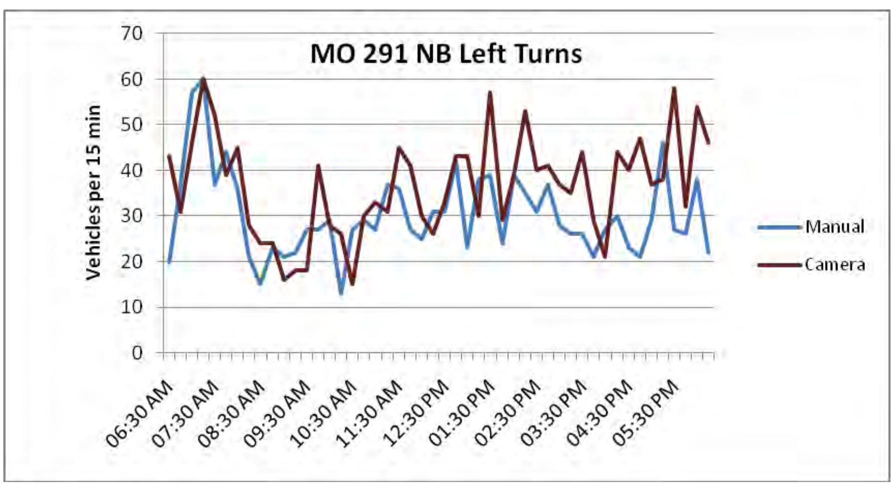
Figure B-1. 15-Minutes Turning Movement Volumes for the Southbound Approach of MO 291 at Chipman Road



12-hr totals	
Manual	Camera
526	1020

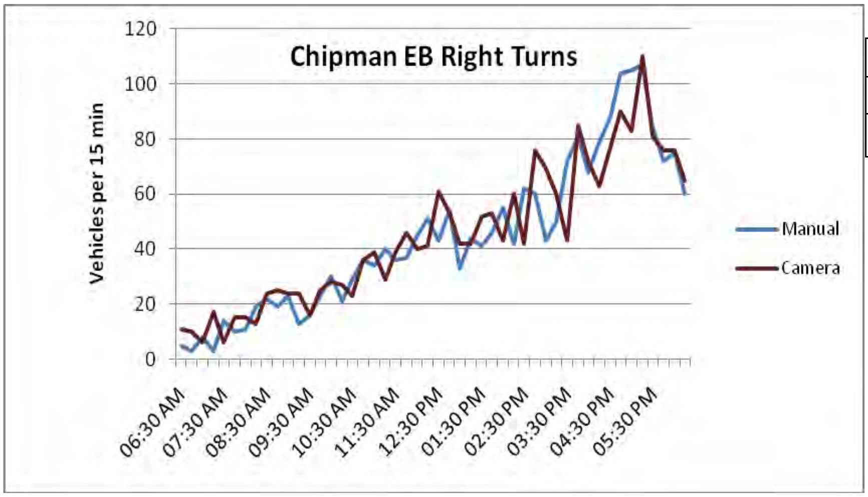


12-hr totals	
Manual	Camera
9679	9483

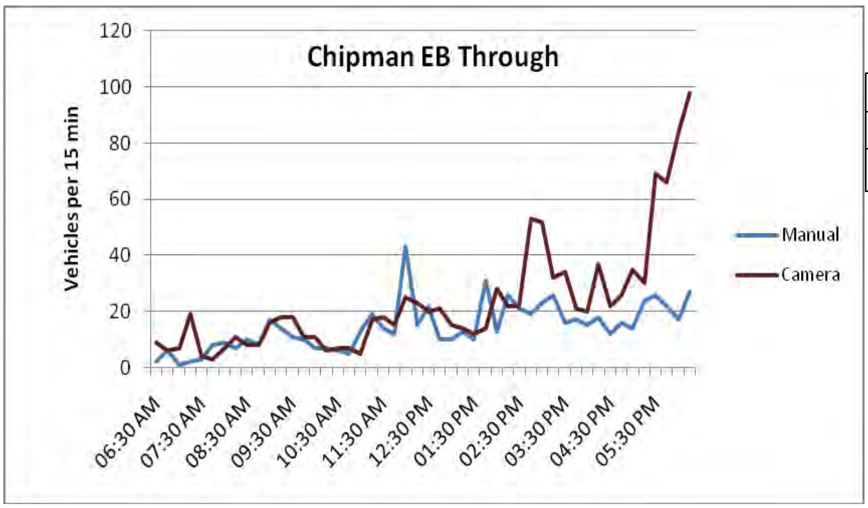


12-hr totals	
Manual	Camera
1457	1760

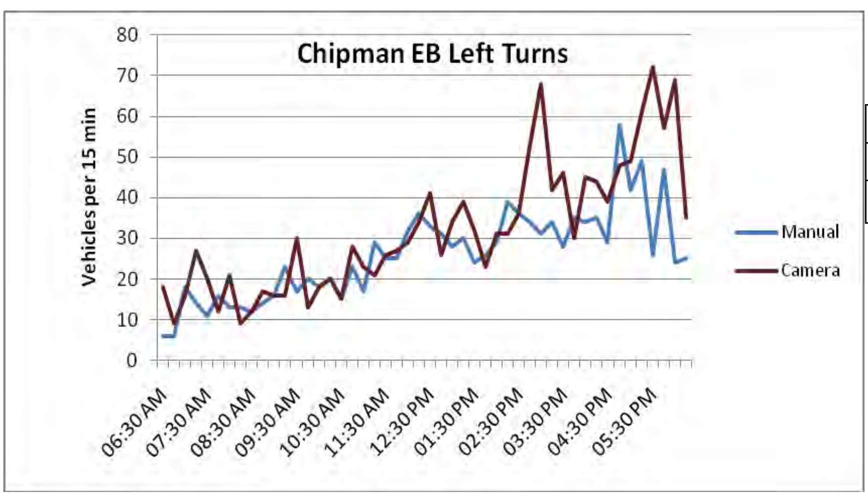
Figure B-2. 15-Minute Turning Movement Volumes for the Southbound Approach of MO 291 at Chipman Road



12-hr totals	
Manual	Camera
2116	2153

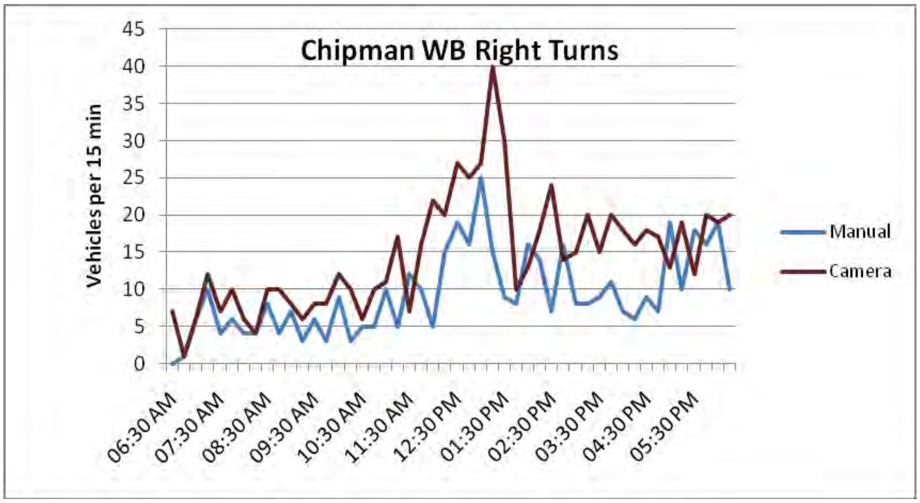


12-hr totals	
Manual	Camera
697	1126

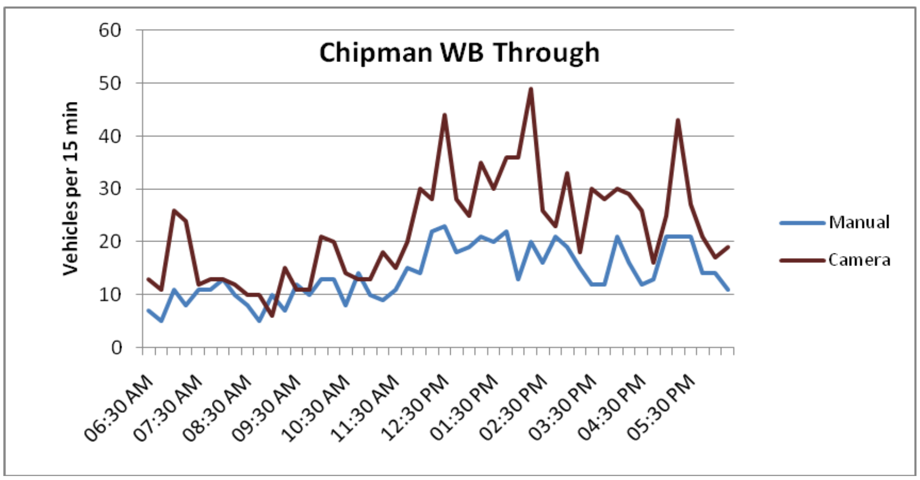


12-hr totals	
Manual	Camera
1246	1528

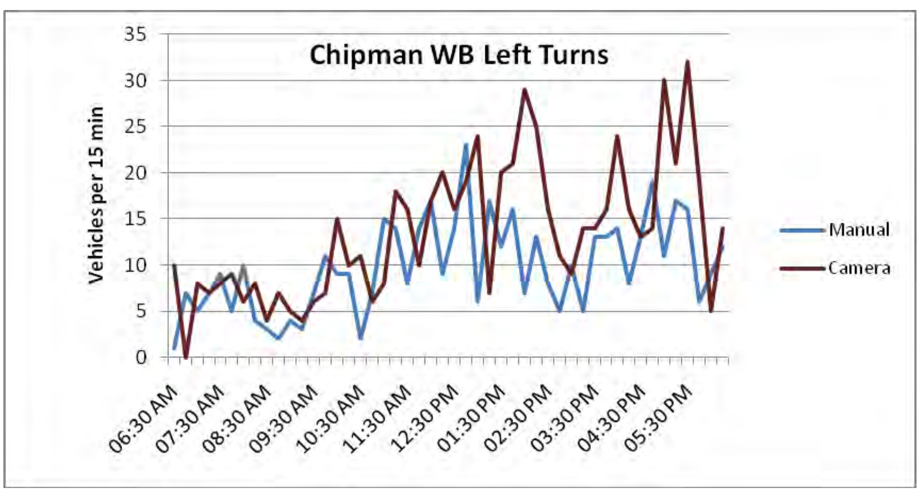
Figure B-3. 15-Minute Turning Movement Volumes for the Eastbound Approach of Chipman Road at MO 291



12-hr totals	
Manual	Camera
447	704



12-hr totals	
Manual	Camera
672	1073



12-hr totals	
Manual	Camera
469	649

Figure B-4. 15-Minute Turning Movement Volumes for the Westbound Approach of Chipman Road

Table B-1. 15-Minute Turning Movement Volumes by Counting Method

	MO-291 from North (SB)						MO-291 from South (NB)					
Start time	Right		Thru		Left		Right		Thru		Left	
	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera
06:30 AM	11	8	72	92	1	7	3	38	162	118	20	43
06:45 AM	17	18	110	82	4	5	1	8	195	171	37	31
07:00 AM	14	22	119	116	3	5	8	9	178	192	57	46
07:15 AM	24	67	144	123	7	2	1	16	233	168	60	60
07:30 AM	29	30	131	144	2	7	7	9	204	227	37	52
07:45 AM	24	35	166	130	7	3	7	13	211	187	44	39
08:00 AM	21	23	160	176	10	11	8	11	193	210	36	45
08:15 AM	22	26	130	162	6	6	7	10	194	184	21	28
08:30 AM	10	24	140	133	6	6	7	15	217	164	15	24
08:45 AM	19	16	161	140	10	8	5	14	175	216	23	24
09:00 AM	12	26	142	164	5	12	9	12	152	159	21	16
09:15 AM	13	20	150	157	8	10	10	11	154	153	22	18
09:30 AM	25	22	159	166	14	5	8	19	150	148	27	18
09:45 AM	19	27	190	164	3	16	8	15	190	164	27	41
10:00 AM	21	25	136	187	8	7	13	18	204	190	29	28
10:15 AM	21	22	159	145	7	10	11	16	172	198	13	26
10:30 AM	23	20	174	145	4	8	7	17	197	167	27	15
10:45 AM	18	32	157	171	8	9	7	18	175	192	29	30
11:00 AM	23	24	190	170	15	9	8	12	177	166	27	33
11:15 AM	16	29	172	180	10	11	16	19	207	200	37	31
11:30 AM	21	23	202	186	21	12	18	24	185	186	36	45
11:45 AM	27	31	200	206	17	21	10	25	187	176	27	41
12:00 PM	30	38	203	209	22	23	19	16	193	195	25	30
12:15 PM	22	30	211	228	33	29	17	28	207	208	31	26
12:30 PM	26	37	197	214	20	24	12	27	204	220	31	33

Table B-1. 15-Minute Turning Movement Volumes by Counting Method (Continued)

	MO-291 from North (SB)						MO-291 from South (NB)					
Start time	Right		Thru		Left		Right		Thru		Left	
	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera
12:45 PM	20	36	212	225	18	22	15	25	251	209	42	43
01:00 PM	21	37	235	228	16	24	23	17	182	231	23	43
01:15 PM	29	31	190	206	13	23	16	35	199	189	38	30
01:30 PM	41	35	164	188	12	22	9	28	195	201	39	57
01:45 PM	23	29	210	217	20	17	16	16	194	203	24	29
02:00 PM	31	30	171	220	13	27	12	22	212	185	39	39
02:15 PM	35	40	210	203	19	18	19	18	211	209	35	53
02:30 PM	25	41	211	215	10	21	13	27	206	180	31	40
02:45 PM	34	55	222	247	18	30	11	23	260	237	37	41
03:00 PM	13	61	226	239	20	54	9	23	223	226	28	37
03:15 PM	23	40	258	251	12	20	11	25	211	224	26	35
03:30 PM	31	58	252	254	22	28	11	20	202	217	26	44
03:45 PM	29	43	291	291	16	22	18	19	193	219	21	29
04:00 PM	22	57	279	245	18	25	11	29	236	188	27	21
04:15 PM	29	48	286	273	31	36	8	17	225	249	30	44
04:30 PM	45	48	278	234	9	29	8	17	196	200	23	40
04:45 PM	28	56	294	288	25	27	9	25	266	216	21	47
05:00 PM	25	50	286	266	10	36	10	21	223	221	29	37
05:15 PM	28	53	303	307	16	20	15	20	249	246	46	38
05:30 PM	28	51	241	262	14	27	11	25	203	222	27	58
05:45 PM	21	45	267	292	24	26	15	35	233	219	26	32
06:00 PM	31	31	235	235	10	26	17	53	195	214	38	54
06:15 PM	25	50	233	238	14	15	12	60	198	219	22	46

Table B-2. 15-Minutes Turning Movement Volumes by Counting Method

	CHIPMAN RD from West (EB)						CHIPMAN RD from East (WB)					
Start time	Right		Thru		Left		Right		Thru		Left	
	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera
06:30 AM	5	11	2	9	6	18	0	7	7	13	1	10
06:45 AM	3	10	6	6	6	9	1	1	5	11	7	0
07:00 AM	8	6	1	7	18	16	6	6	11	26	5	8
07:15 AM	3	17	2	19	14	27	10	12	8	24	7	7
07:30 AM	14	6	3	4	11	20	4	7	11	12	9	8
07:45 AM	10	15	8	3	16	12	6	10	11	13	5	9
08:00 AM	11	15	9	7	13	21	4	6	13	13	10	6
08:15 AM	19	13	7	11	13	9	4	4	10	12	4	8
08:30 AM	22	24	10	8	12	12	8	10	8	10	3	4
08:45 AM	19	25	8	8	14	17	4	10	5	10	2	7
09:00 AM	23	24	17	16	16	16	7	8	10	6	4	5
09:15 AM	13	24	14	18	23	16	3	6	7	15	3	4
09:30 AM	16	16	11	18	17	30	6	8	12	11	7	6
09:45 AM	23	25	10	11	20	13	3	8	10	11	11	7
10:00 AM	30	28	7	11	18	18	9	12	13	21	9	15
10:15 AM	21	27	7	6	20	20	3	10	13	20	9	10
10:30 AM	29	23	6	7	15	15	5	6	8	14	2	11
10:45 AM	36	36	5	7	23	28	5	10	14	13	7	6
11:00 AM	34	39	13	5	17	23	10	11	10	13	15	8
11:15 AM	40	29	19	17	29	21	5	17	9	18	14	18
11:30 AM	36	39	14	18	25	26	12	7	11	15	8	16
11:45 AM	37	46	12	15	25	27	10	16	15	20	14	10
12:00 PM	45	40	43	25	32	29	5	22	14	30	17	17
12:15 PM	51	41	15	23	36	34	15	20	22	28	9	20
12:30 PM	43	61	22	20	33	41	19	27	23	44	14	16

Table B-2. 15-Minutes Turning Movement Volumes by Counting Method (Continued)

	CHIPMAN RD from West (EB)						CHIPMAN RD from East (WB)					
Start time	Right		Thru		Left		Right		Thru		Left	
	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera	Manual	Camera
12:45 PM	54	53	10	21	31	26	16	25	18	28	23	19
01:00 PM	33	42	10	15	28	34	25	27	19	25	6	24
01:15 PM	44	42	13	14	30	39	15	40	21	35	17	7
01:30 PM	41	52	10	12	24	32	9	30	20	30	12	20
01:45 PM	46	53	31	14	26	23	8	10	22	36	16	21
02:00 PM	55	43	13	28	29	31	16	13	13	36	7	29
02:15 PM	42	60	26	22	39	31	14	18	20	49	13	25
02:30 PM	62	42	21	22	36	36	7	24	16	26	8	16
02:45 PM	60	76	19	53	34	53	16	14	21	23	5	11
03:00 PM	43	69	23	52	31	68	8	15	19	33	10	9
03:15 PM	50	60	26	32	34	42	8	20	15	18	5	14
03:30 PM	72	43	16	34	28	46	9	15	12	30	13	14
03:45 PM	81	85	17	21	35	30	11	20	12	28	13	16
04:00 PM	68	72	15	20	34	45	7	18	21	30	14	24
04:15 PM	79	63	18	37	35	44	6	16	16	29	8	16
04:30 PM	88	77	12	22	29	39	9	18	12	26	13	13
04:45 PM	104	90	16	26	58	48	7	17	13	16	19	14
05:00 PM	105	83	14	35	42	49	19	13	21	25	11	30
05:15 PM	107	110	24	30	49	61	10	19	21	43	17	21
05:30 PM	84	81	26	69	26	72	18	12	21	27	16	32
05:45 PM	72	76	22	66	47	57	16	20	14	21	6	19
06:00 PM	75	76	17	84	24	69	19	19	14	17	9	5
06:15 PM	60	65	27	98	25	35	10	20	11	19	12	14

Missouri Department of Transportation
Organizational Results
P. O. Box 270
Jefferson City, MO 65102

573.526.4324
1 888 ASK MODOT
innovation@modot.mo.gov